AMIANTIT QATAR PIPES CO. LTD

ENGINEERING GUIDE

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1 FOREWORD

AQAP GRP/GRP continuous filament wound piping systems with inheritent corrosion and weathering resistance as well as superior strength to weight ratio are widely used for severe operating conditions for several industrial and municipal applications.

The purpose of the AQAP Engineering Guide is to provide engineers with a useful tool for the design, specification of AQAP Pipes (glass-fiber-reinforced thermosetting-resin pipe), pipes and fittings installation manual the guidelines for their installation for aboveground self-restrained systems.

The information provided by this AQAP Engineering Guide are widely applicable to diameter size ranging from 25 to 4000 mm. Anyway, for diameter larger than ND1200 or for not standard applications it is suggested to contact the technical department of Amiantit Qatar to identify the appropriate solutions.

FIELDS COVERED BY AMIANTIT PRODUCTS ARE THE FOLLOWING:

A. Water Distribution (civil and industrial).
B. Sewer Systems (urban and industrial).
C. Irrigation Networks.
D. Water Intakes for Cooling Water Systems.
E. Waste Water Outfalls to sea.
F. Sub-sea Pipelines.
G. Process Lines for Industrial plants.
H. Fire Fighting Networks.
I. Marine pipes & Offshore Pipes.

2 CODES AND STANDARDS

The governing documents commonly used in specifying, testing, and applying GRP piping are the following:

PRODUCT SPECIFICATIONS AND CLASSIFICATIONS	
ANSI/AWWA C950	Standard for Fiberglass Pressure Pipe.
ASTM D2310	Standard Classification for Machine-Made Reinforced Thermosetting-Resin Pipe.
ASTM D2996	Standard Specification for Filament-Wound “Fiberglass” (Glass-Fiber Reinforced Thermosetting-Resin) Pipe.
ASTM D3262	Standard Specification for “Fiberglass” (Glass-Fiber-Reinforced Thermosetting-Resin) Sewer Pipe.
ASTM D3517	Standard Specification for “Fiberglass” (Glass-Fiber-Reinforced Thermosetting-Resin) Pressure Pipe.
ASTM D3754	Standard Specification for “Fiberglass” (Glass-Fiber-Reinforced Thermosetting-Resin) Sewer and Industrial Pressure Pipe.
ASTM D4161	Standard Specification for “Fiberglass” (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe Joints Using Flexible Elastomeric Seals.
BS EN 1796	Plastics piping systems for water supply with or without pressure- Glass-reinforced thermosetting plastics (GRP) based on the unsaturated polyester resin (UP).
BS EN 14364	Plastics piping systems for drainage and sewerage with or without pressure. Glass-reinforced thermosetting plastics (GRP) based on the unsaturated polyester resin (UP) – specification for pipes, fittings, and joints.
ISO 14692	Petroleum and natural gas industries – Glass-reinforced plastics (GRP) piping.
API 15 LR	Specification for Low-Pressure Fiberglass Line Pipe and Fittings

RECOMMENDED PRACTICES	
ASTM C581	Standard Practice for Determining Chemical Resistance of Thermosetting Resins Used in Glass-Fiber-Reinforced Structures Intended for Liquid Service.
ASTM D2488	Standard Practice for Description and Identification of Soils.
ASTM D2992	Standard Practice for Obtaining Hydrostatic or Pressure Design Basis for “Fiberglass” (Glass-Fiber-Reinforced Thermosetting-Resin) Pipes and Fittings Procedure B – Steady Pressure.
ASTM D3567	Standard Practice for Determining Dimensions of Reinforced Thermosetting Resin Pipe (RTRP) and Fittings.
ASTM D3839	Standard Practice for Underground Installation of “Fiberglass” (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe
ISO 14692	Petroleum and natural gas industries – Glass-reinforced plastics (GRP) piping

TEST METHODS	
ASTM D1598	Standard Test Method for Time-to-Failure of Plastic Pipe Under Constant Internal Pressure
ASTM D1599	Standard Test Method for Short Term Hydraulic Failure Pressure of Plastic Pipe, Tubing and Fittings
ASTM D2412	Standard Test Method for Determining of External Loading Characteristics of Plastics Pipe by Parallel-Plate Loading
ASTM D2924	Standard Test Method for External Pressure Resistance of Reinforced Thermosetting-Resin Pipe
ASTM D3681	Standard Test Method for Chemical Resistance of “Fiberglass” (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe in a Deflected Condition
ISO 14692	Petroleum and natural gas industries – Glass-reinforced plastics (GRP) piping

3 PRODUCT CODIFICATION:

GRP/GRP/GRV Pipes products are specified hereunder for different applications:

AQAP GRV1: GRV Pipes with Vinlylester Bisphenol A resin, self-restrained for underground or above-ground applications.

AQAP GRV2: GRV Pipes with Vinlyester Novalac resin, self-restrained for underground or above-ground applications.

Then one more letter is added as below:

C: External Conductive pipes
CC: Full Conductive Pipes
Fire-rated as per ASTM E 84 class A or B: FA or FB
Potable water: P

Example 1: AQAP GRV2 FA, GRV pipes Novalac and fire rated Class A

4 CLASSIFICATION OF PIPES AND FITTINGS

Nominal Diameter

The nominal size of pipes and fittings is based on internal diameter. The complete list of the available size produced by Amiantit is in table 4-1.

Nominal Pressure Classes

Pipes and fittings are classified according to nominal pressure. Standard pressure classes are 6, 10, 12, 16, 20, 25. 32, 40, 50 bar. Intermediate pressure up to 50 bar classes are considered on request or depending on the design conditions. Below table 4-1 shows pressure limitation for each pipe diameter.

Table 4-1

	PN-6	PN-10	PN-12	PN-16	PN-20	PN-25	PN-32
DN							
25	■	■	■	■	■	■	■
40	■	■	■	■	■	■	■
50	■	■	■	■	■	■	■
80	■	■	■	■	■	■	■
100	■	■	■	■	■	■	■
150	■	■	■	■	■	■	■
200	■	■	■	■	■	■	■
250	■	■	■	■	■	■	■
300	■	■	■	■	■	■	■
350	■	■	■	■	■	■	
400	■	■	■	■	■	■	
450	■	■	■	■	■	■	
500	■	■	■	■	■	■	
600	■	■	■	■	■	■	
700	■	■	■	■	■	■	
750	■	■	■	■	■	■	
800	■	■	■	■	■	■	
900	■	■	■	■	■	■	
1000	■	■	■	■	■	■	
1100	■	■	■	■	■		
1200	■	■	■	■	■		
1300	■	■	■	■	■		
1400	■	■	■	■	■		
1500	■	■	■	■	■		
1600	■	■	■	■	■		
1700	■	■	■	■	■		
1800	■	■	■	■	■		
1900	■	■	■	■	■		
2000	■	■	■	■	■		
2100	■	■	■	■			
2200	■	■	■	■			
2300	■	■	■	■			
2400	■	■	■	■			
2500	■	■					
2600	■	■					
2800	■	■					
3000	■	■					
3200	■	■					
3400	■	■					
3600	■	■					
4000	■	■					

Specific Pipe Stiffness Classes

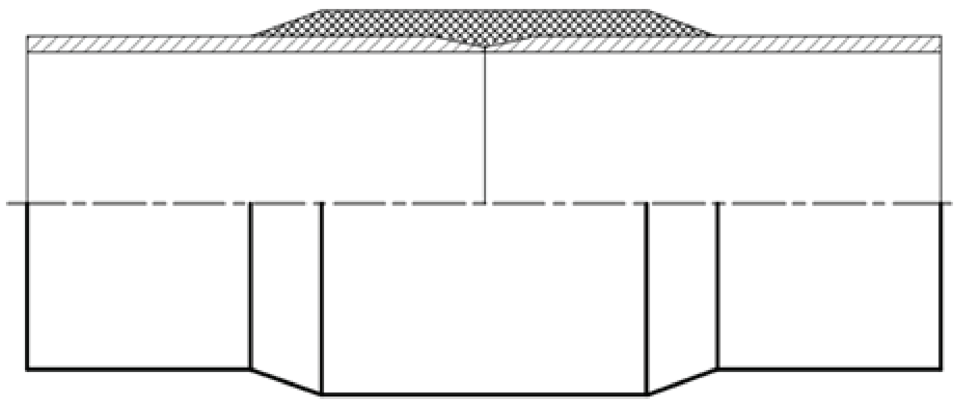
Pipes are also classified according to specific pipe stiffness classes: 2500, 5000, and 10000 Pa. Intermediate or higher stiffness classes are available on request or depending on the design conditions.

The standard GRP pipes and fittings produced by Amiantit are described in the Product Guide.

4.1 SELF-RESTRAINED JOINT

A. Laminate joint (LJ)

Generally, this type of joint is only used on diameters over 400mm.
The preparation of this rigid joint requires good craftsmanship; it is recommended that Amiantit Qatar provides the training and assistance during installation.

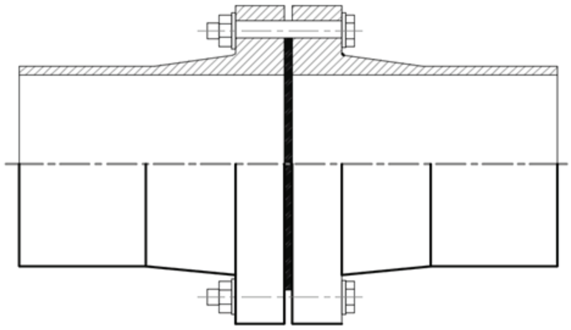


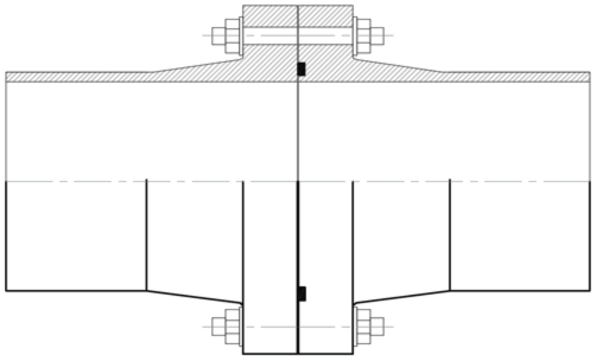
B. Flange joint (FJ)

To enable connection with steel piping and to allow for easy assembling and disassembling of process lines, AQAP pipes and fittings can be supplied with flanges, drilled in accordance with ASME, EN or other standards.

Special requirement can also be met upon request.

AQAP glass fiber reinforced epoxy flanges are always flat faced. However large dia flanges are produced with hand lay up process is coming with groove face suitable for O ring gaskets, refer to AQAP product guide for Flange details.



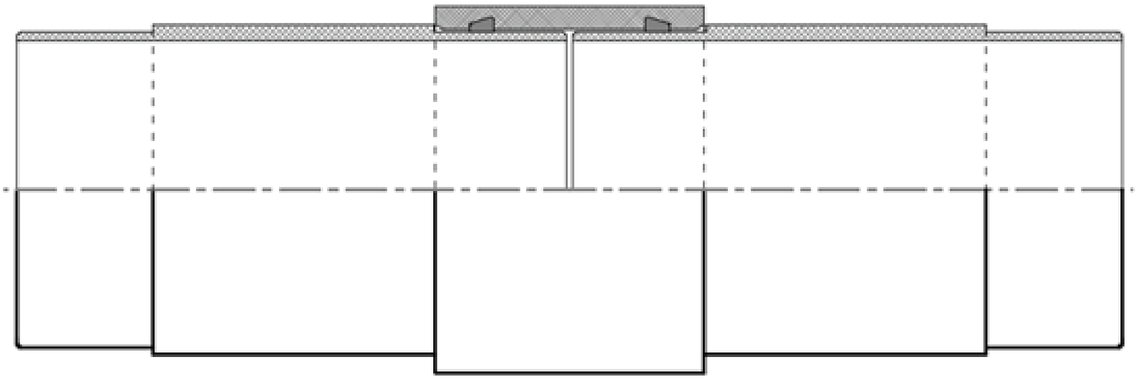


4.2 NON-RESTRAINED JOINT

A. Double Bell Coupling

The double bell coupling is provided with two profile groove to suit rubber rings REKA type with high tightness.

This flexible joint allows for some axial movement of the spigot in the socket and some angular deflection.



B. Mechanical coupler (MC)

A mechanical coupler normally consists of a metal casing and a rubber seal.
This joint is available in different versions and is mostly non-thrust resistant. In these joints the sealing is obtained on the (machined) surfaces of plain-ended pipes. The maximum allowable pressure will depend on the type of coupler.

5 PIPE DESIGN DATA

A. MINIMUM REINFORCED WALL THICKNESS DUE TO INTERNAL PRESSURE

The minimum reinforced wall thickness related to pressure rating is calculated using of below formulas:

Formula 5A1: Derived from ASTM D 2992

$$t_r = \frac{PD_o}{(2\sigma_h + P)}$$

t_r : Minimum reinforced wall thickness (mm)
$^{\sigma}h$: Allowable Hoop Stress (Mpa). Σh = F × HDB
F : Service Factor
HDB : Hydrostatic Design Basis, Hoop stress (Mpa)
D_i : Average reinforced inner diameter
P : Pressure Rating
D_o : Outer diameter

Formula 5A2: Derived from API 15 LR and 15 HR.

$$P_s = (0.67)\frac{2S_s t_r}{D_m} \; ; \; t_r = \frac{P_s D_m}{(0.67)2S_s} \; \text{(Static)}$$

$$P_c = \frac{2S_c t_r}{D_m} \; ; \; t_r = \frac{P_c D_m}{2S_c} \; \text{(Cyclic)}$$

t_r : Minimum reinforced wall thickness (mm)
S_s : 95% (LCL) of the LTHS @20 years (N/mm^2)
S_c : 150x10 cylic
D_m : Mean Diameter (mm)
P_s : Internal Static Pressure (N/mm^2)
P_c : Internal Cyclic Pressure (N/mm^2)

Due to the production process, the actual wall thickness may be larger than the calculated minimum value.

B. TOTAL WALL THICKNESS

Formula 5B1: Wall Thickness (t)

$$t = t_r + t_l + t_e$$

t	:	Total wall thickness (mm)
t_r	:	Minimum reinforced wall thickness (mm)
t_l	:	Liner thickness 0.50mm for standard AQAP Pipe
t_e	:	External Layout

C. DIAMETERS

Formula 5C1: Average Outside Diameter (D_o)

$$D_o = D_i + 2t_r$$

D_o	:	Average outside diameter (mm)
D_i	:	Average reinforced inner diameter (mm)
t_r	:	Minimum reinforced wall thickness (mm)

Formula 5C2: Mean Diameter (D_m)

$$D_m = D_i + t_r$$

D_m	:	Mean diameter (mm)
D_i	:	Average reinforced inner diameter (mm)
t_r	:	Minimum reinforced wall thickness (mm)

Formula 5C3: Average Reinforced Inner Diameter (D_i)

$$D_i = d_i + 2t_i$$

D_i	:	Average reinforced inner diameter (mm)
d_i	:	Pipe’s inner diameter (mm)
t_i	:	liner thickness (mm)

D. PIPE CROSS-SECTIONAL AREA

Formula 5D1: Inner Pipe Cross-Sectional Area (A_i)

$$A_i = \frac{\pi}{4}(d_i)^2$$

A_i : Inner Pipe Cross-Sectional Area (mm^2)
d_i : Pipe's inner diameter (mm)

Formula 5D2: Cross-sectional area of minimum structural pipe wall (A_s)

$$A_s = \pi(D_i + t_r)(t_r)$$

A_s : Cross-sectional area of min. structural pipe wall (mm^2)
D_i : Average reinforced inner diameter (mm)
t_r : Minimum reinforced wall thickness (mm)

Formula 5D3: Cross-sectional area of inner pipe liner (A_l)

$$A_l = \pi(d_i + t_l)(t_l)$$

A_l : Cross-sectional area of inner pipeline (mm^2)
d_i : Pipe's inner diameter (mm)
t_l : Liner thickness = 0.5(mm): for standard AQAP pipe

Formula 5D4: Cross-sectional area of the pipe (A)

$$A = A_s + A_l$$

A : Cross-sectional area of the pipe (mm^2)
A_s : Cross-sectional area of min. structural pipe wall (mm^2)
A_l : Cross-sectional area of inner pipeline (mm^2)

E. PIPE WEIGHT

Formula 5E1: Pipe's Self Weight (W_f)

$$W_f = A_i \rho_f \bullet 9.81 \bullet 10^{-6}$$

W_f	:	Fluid weight (N/m)
A_i	:	Inner pipe cross-sectional area (mm^2)
ρ_f	:	Density of fluid (kg/m^3)

F. PIPE'S LINEAR MOMENT OF INERTIA

Formula 5F1: Moment of Inertia of Structural Wall Rotation (I_s)

$$I_s = \frac{\pi}{64}\left({D_o}^4 - {D_i}^4\right)$$

I_s	:	Moment of inertia of structural wall (mm^4)
D_o	:	Average outside diameter (mm)
D_i	:	Average reinforced inner diameter (mm)

Formula 5F2: Moment of Inertia of Liner rotation (I_l)

$$I_l = \frac{\pi}{64}\left({D_i}^4 - {d_i}^4\right)$$

I_l	:	Moment of inertia of Liner (mm^4)
D_i	:	Average reinforced inner diameter (mm)
d_i	:	Pipe's inner diameter (mm)

Formula 5F3: Moment of Inertia of the Pipe rotation (I)

$$Irr = I_s + I_l$$

Irr	:	Moment of inertia of the Pipe rotation (mm^4)
I_s	:	Moment of inertia of structural wall (mm^4)
I_l	:	Moment of inertia of Liner (mm^x)

Formula 5F4: Moment of Inertia of the Pipe bending (I)

$$\mathrm{Ixx} = \frac{Irr}{2}$$

Ixx : Moment of inertia of the Pipe bending (mm^4)

G. EXTERNAL PRESSURE

Plain pipe and fittings shall have sufficient stiffness to resist vacuum and /or external pressure loads. The minimum stiffness shall be sufficient to resist a short-term vacuum (e.g., by the operation of an upstream valve) with a safety factor F_e of 1,5.

Piping susceptible to long-term vacuum and/or external pressure loads like marine pipes service, shall have a stiffness sufficient to resist the induced with a safety factor F_e of 3,0.

The external collapse pressure, P_e, in MPa, of GRP pipes shall be calculated Formula 5G1 which assumes that the length of the pipe is significantly greater than the diameter:

Formula 5G1: External Pressure (P_e)

$$P_e = 2 * \frac{1}{F_e} * E_{hb} * \left(\frac{t_{r,min}}{D_{r,min}}\right)^3$$

F_e : is the safety factor, equal to 3,0.
E_{hb} : is the hoop bending modulus, expressed in MPa.
$t_{(r,min)}$: is the minimum reinforced pipe wall thickness, expressed in mm.
$D_{(r,min)}$: is the mean diameter of the minimum reinforced pipe wall, expressed in mm.

H. PIPE STIFFNESS

Formula 5H1: STIS: Specific Tangential Stiffness (STIS)

$$\mathrm{STIS} = \frac{E_c}{12}\left(\frac{t}{D_i+t}\right)^3$$

STIS : Specific tangential stiffness (Pa)
D_i : Mean diameter
E_c : Circumferential modulus of elasticity (N/mm2)
t : total wall thickness (mm)

Formula 5H2: PS: Pipe Stiffness, by parallel plate load test per ASTM D2412 (PS)

$$PS = 1000 \frac{F}{\Delta y_t}$$

PS : Pipe Stiffness (kPa)
F : Load per unit length (N/mm)
Δy_t : Vertical pipe deflection (mm), per ASTM D2412 with a 5% deflection

Formula 5H3: PS: Pipe Stiffness, using pipe dimension and material property (PS)

$$PS = \frac{EI_t \bullet 10^6}{0.149\left(r_m + \frac{\Delta y_t}{2}\right)^3}$$

PS : Pipe Stiffness (kPa)
E : Ring modulus of elasticity (Gpa)
I_t : Moment of inertia of pipe wall/unit length
: $t^3/12$ (mm^4/mm)
r_m : Mean pipe radius (mm) = $D_m/2$
D_m : Mean diameter (mm)
Δy_t : Vertical pipe deflection (mm), per ASTM D2412 with a 5% deflection

Formula 5H4: PS: Pipe Stiffness, using pipe dimension and material property (SF)

$$F = 0.149 r^3{}_m PS \bullet 10^{-6}$$

SF : Stiffness Factor (kPa)
r_m : Mean pipe radius (mm)
PS : Pipe Stiffness (kPa)

6 PROPERTIES OF LAMINATES

The following tables is representing GRP/GRV pipes produced on continuous winding machine full glass pipes for self-restrained systems.

6.1 MECHANICAL PROPERTIES

Tab 6-1 – Mechanical Properties

Physical and Mechanical Properties				
Pipe Property	Symbol	Units	Test Method	GRP / GRV
Nominal Pipe Size	DN	in , mm		> = 8" (200 mm)
Hydrostatic design basis (static) stress based , 50 years	HDB	Mpa	ASTM D 2992	109 @ 23° C
				72 @ 45° C
Circumferential Tensile Stress (weeping)	CTS	Mpa	ASTM D 1599	190
Hoop Tensile Modulus	Eh	Mpa	ISO 14692	26000
Longitudinal Tensil Strength @ 23°C	LTS	Mpa	D 638	70
Axial Tensile Tensile Modulus @ 23°C	Ea	Mpa	D 638	11500
Poisson's ratio hoop loading	ν h/a	-	ISO 14692	0.37
Poisson's ratio axial loading	ν a/h	-	ISO 14692	0.16
Shear Modulus	G	Mpa		4600

6.2 THERMAL AND OTHER PHYSICAL PROPERTIES

Table 6.2 – Thermal and Physical Properties

7 HEAD LOSS IN PIPES & FITTINGS

7.1 AQAP PIPES

AQAP pipeline systems have a relatively low head loss due to the smooth inner surface of the products. The head losses have been determined by using the Darcy-Weisbach formula.

The fluid velocity limitation will be up to 4 m/s for AQAP Pipes for standard fluid and for high abrassive fluid it is limited to 3 m/s. However for occasional fluid limit it may goes to 5 m/s.

The friction coefficients for the pipeline system are determined by the Colebrook-White method using wall roughness k. or using Hazen-Williams formula.

Head loss flow charts for pipes are shown in Figure 7.1 and 7-2, These figures give the head loss in the pipeline system in metre head of water per metre pipe length for water at 10 °C. At higher operating temperatures the kinematical viscosity of water decreases, resulting in lower head losses.

Figure 7-1 – Head loss flow chart ID 25mm through 300mm

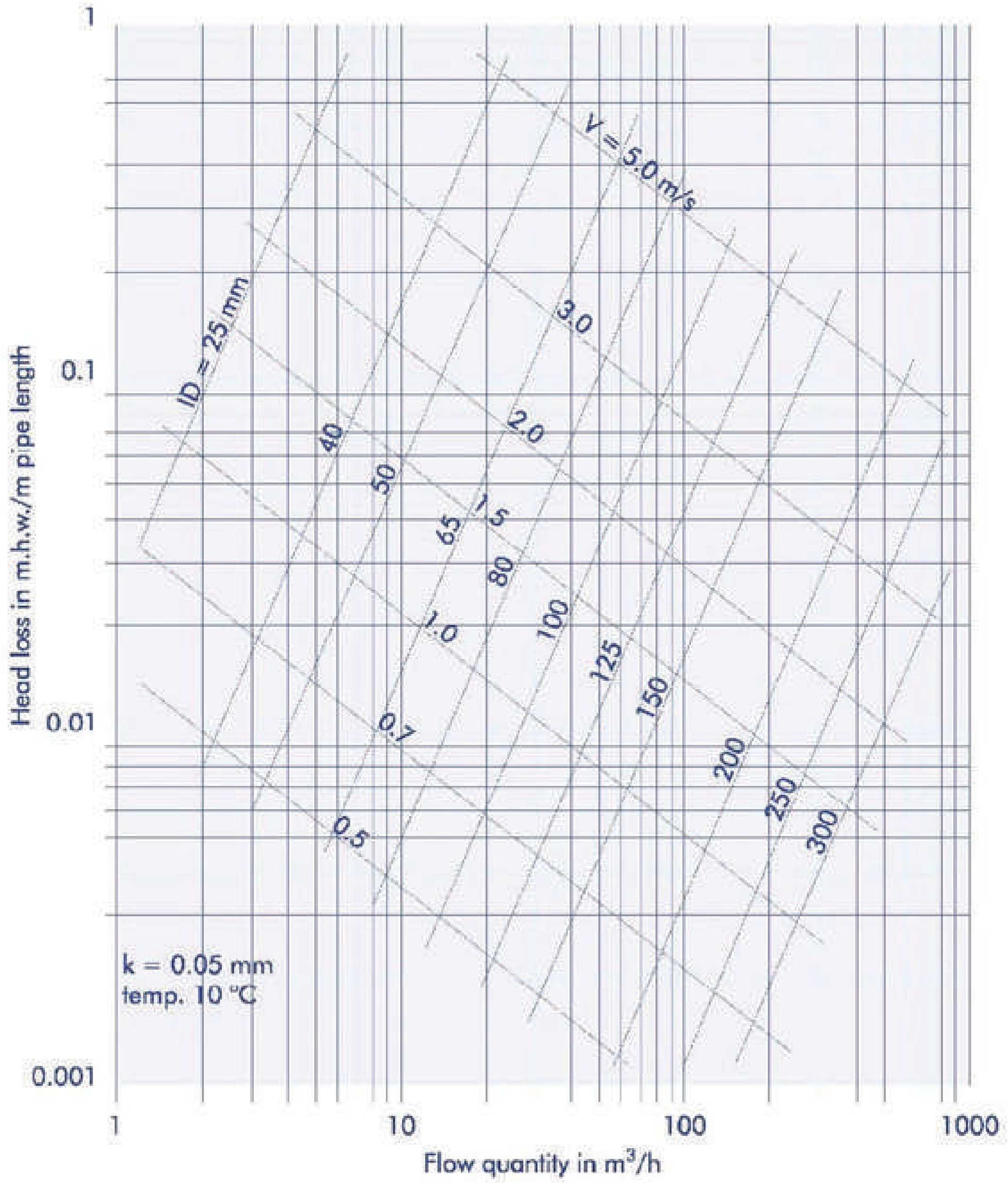
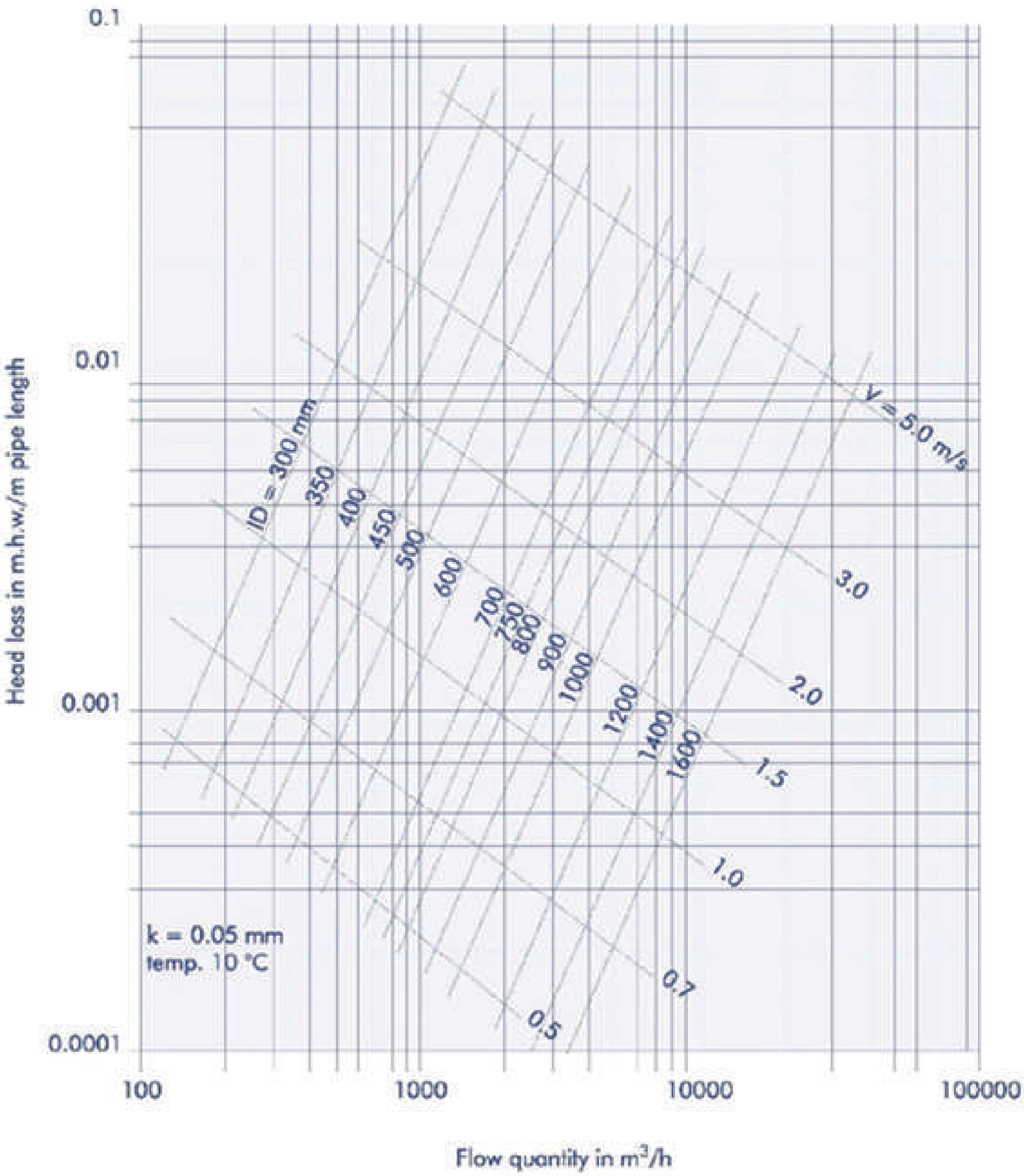


Figure 7-2 – Head loss flow chart ID 300mm through 1600mm



7.2 AQAP FITTINGS

The head loss in fittings can be calculated from the following formula:

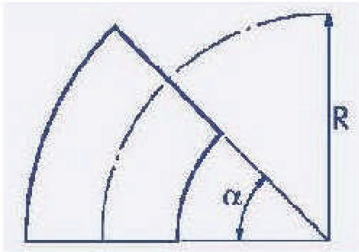
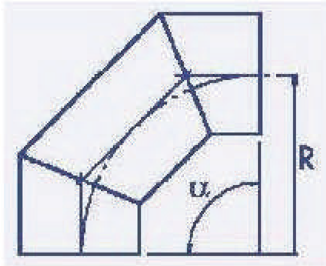
Formula 10A: ($\Delta H_{fittings}$)

$$\Delta H_{fittings} = \Sigma * \frac{1}{2} * \rho * V^2$$

$\Delta H_{fittings}$: Head loss in the fitting
Σ : Friction coefficient
ρ : Specific gravity of the fluid
V : Flow velocity

Joint: Lamination joint without internal lamination, or KB= 0, Laminated _.

7.3 FRICTION COEFFICIENT ζ (-) FOR ELBOWS

DN Range	Bend Angle		
DN =< 450	1 - 30 °	-	0.14
	31 - 60 °	0.11	0.23
	61 - 90 °	0.16	0.38
DN > 450	1 - 30 °	-	0.15
	31 - 60 °	-	0.24
	61 - 90 °	-	0.4

STD bend radius is 1.5 DN

7.4 FRICTION COEFFICIENT ζ (-) FOR REDUCER

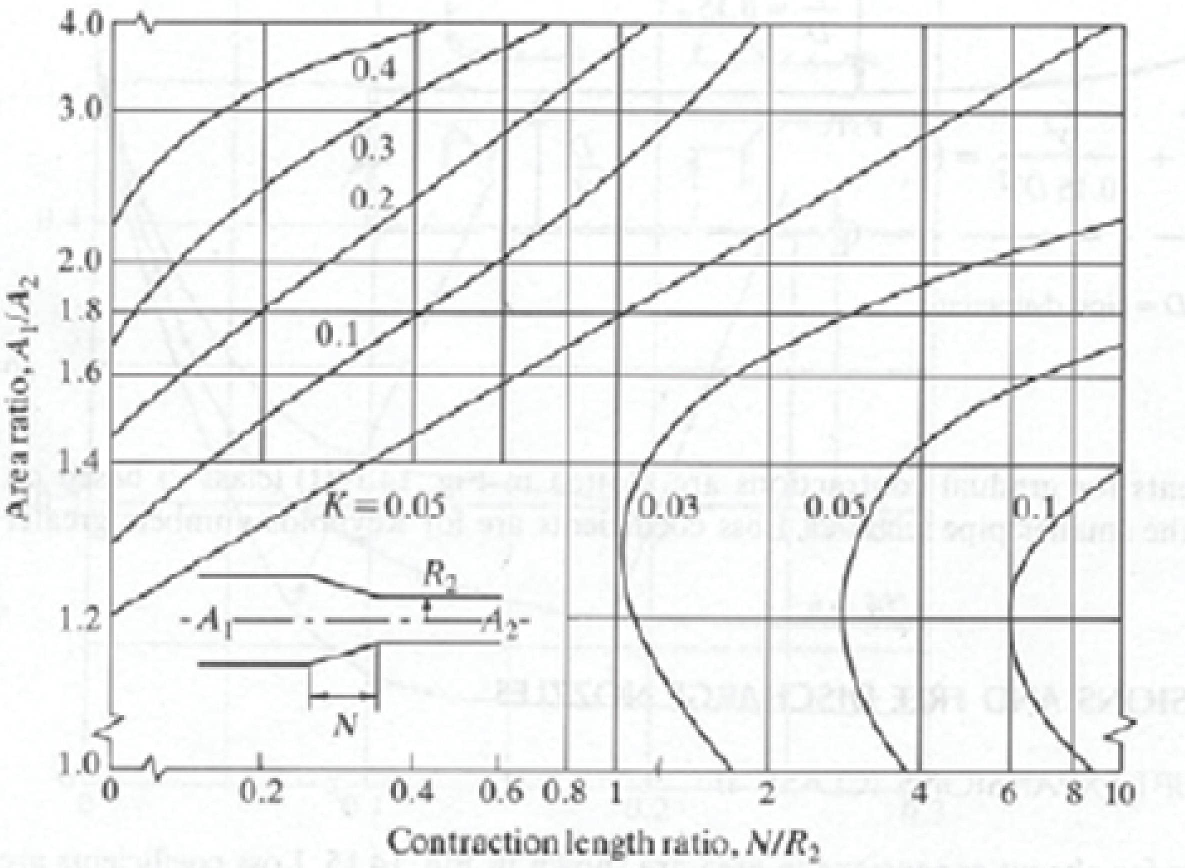


Figure 7-4 Loss factors for reducers Kb. The factor is based on the flow in the downstream pipe.

For AQAP reducers, the specified length is: **$N = 2{,}5^{*} (D_L\text{-}D_S)$**

From this graph and including other losses, the loss coefficient for a DN1800-1600 is:

$$Kb = K_b {*} C_f {*} C_{Re} {*} C_o + K_{Lam}$$

$$= 0{,}05 \times 1{,}09 \times 1{,}0 \times 1{,}0 + 0{,}02$$

$$= 0{,}075$$

K_b : from figure 7-4

C_f : equal to f_{rough} / f_{smooth} typical values as per below:

DN 300 = 1.15

DN 600 = 1.13

DN 900 = 1.12

DN 1200 = 1.1

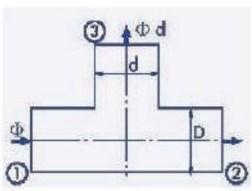
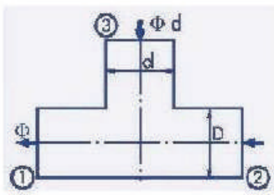
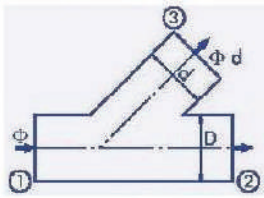
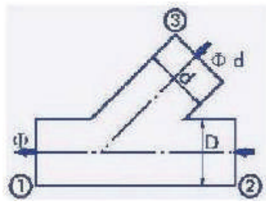
DN 1800 and above = 1.09

C_{Re}: equal to 1 for all cases with Re = .08 * 10^6 to 6.3 *10^6

C_0 : equal to 1 for outlet longer than 30 times Diameter

K_{Lam} : 0.01 for each internal laminate joint

For other reducers, the same calculation procedure applies

		Flow separation		Flow combination		Flow separation		Flow combination	
									
Φd / Φ	d / D	ζ	ζd	ζ	ζd	ζ	ζd	ζ	ζd
0	1	0.04	0.95	0.04	-1.20	0.04	0.90	0.04	-0.92
	0.58	0.25	1.30	0.20	-0.70	0	1.00	0	-1.00
	0.35	0	1	0	-1.00	0	2.00	0	-1.00
0.2	1	-0.08	0.88	0.17	-0.40	-0.06	0.68	0.17	-0.38
	0.58	-0.20	1.55	0.45	0.20	-0.15	0.45	0.10	-0.10
	0.35	0	3.00	0	2.00	-0.10	2.00	0	2.00
0.4	1	-0.05	0.89	0.30	0.08	-0.04	0.50	0.19	0
	0.58	-0.10	2.40	0.75	1.30	0	0.60	-0.15	0.75
	0.35	0	9.00	0	12.00	0	6.00	-1.10	9.00
0.6	1	0.07	0.95	0.41	0.47	0.07	0.38	0.09	0.22
	0.58	0	4.25	1.00	2.80	0.15	1.30	-0.06	2.15
	0.35	0	19.00	0	29.00	0.10	14.00	-2.90	20.00
0.8	1	0.21	1.10	0.51	0.72	0.20	0.35	-0.17	0.37
	0.58	0.25	7.10	1.25	4.80	0.25	2.80	-1.50	3.75
	0.35	0	33.00	0	0	0.20	27.00	-5.70	35.00
1	1	0.35	1.28	0.60	0.91	0.33	0.48	-0.54	0.37
	0.58	0.30	0	1.50	7.25	0.35	4.90	-2.90	5.40
	0.35	0	0	0	0	0.40	44.00	-9.60	54.00

ζ = friction coefficient for pressure loss of ② relative to ①
ζd (flow separatior = friction coefficient for pressure loss of ③ relative to ①
ζd (flow combinati = friction coefficient for pressure loss of ① relative to ③
Φ = flow in the run
Φd = flow in the branch

8 FLUID (WATER) HAMMER

Fluid (water) hammer can be defined as the occurrence of a pressure change in a closed piping system, caused by a change in the flow velocity.

Therefore, fluid (water) hammer can occur in all kinds of piping systems used for the transport of liquids. The greater and faster the velocity change, the greater the pressure change will be. The relation between change of velocity and pressure change can be derived from the formula of Joukowsky:

$$\Delta P = \frac{c}{g} * \Delta v$$

ΔP	:	Pressure change
c	:	Wave velocity
g	:	Acceleration due to gravity
Δv	:	Change in flow velocity

In accordance with AWWA M45, a transient pressure increase of 1.4 times the design pressure is allowable; this is also valid for the AQAP piping system.

The wave velocity (c) depends on the type of fluid, pipe dimensions, and E-modulus. The wave velocity can be calculated with the aid of the Talbot equation:

Formula 8B: (C)

$$c = \frac{1000}{\sqrt{S_V * \left[\frac{1}{K_V} + \frac{ID}{T_E * E_V} * f\right]}}$$

c	:	Wave velocity
S_V	:	Specific gravity of the fluid
K_V	:	Compression modulus of the fluid
ID	:	Inner diameter
T_E	:	Minimum reinforced wall thickness
E_V	:	Volumetric E-modulus
f	:	Constant

For isotropic materials, the volumetric E-modulus is equal to the E-modulus.
For an-isotropic materials, where the material characteristics are dependent on the winding angle (ω), the volumetric E-modulus (E_V) is calculated from the following equation:

Formula 8C: (E_V)

$$E_V = \frac{\sqrt[3]{E_X * E_H^2}}{1 - N_{XY} * N_{YX}}$$

E_V	:	Volumetric E-modulus
E_X	:	Axial bending modulus
E_H	:	Hoop bending modulus
N_{XY}	:	Poisson ratio axial/hoop
N_{YX}	:	Poisson ratio hoop/axial

The constant (f) in the Talbot equation depends on the type of anchoring of the system.

A. The pipeline may be anchored up-stream; in this case, the system is loaded bi-axially.
This can be achieved in a tensile resistant piping system.

Formula 8D:

$$f1 = \frac{5}{4} - 0.5 * N_{XY} * N_{YX}$$

B. The pipeline may be anchored completely to prevent axial displacement.
This may occur in tensile resistant and non-tensile resistant piping systems.

Formula 8E:

$$f2 = 1 - N_{XY} * N_{YX}$$

C. The pipeline may be installed with expansion joints so that there will be no axial stresses.
This will happen in the case of non-tensile-resistant pipelines.

Formula 8F:

$$f3 = 1 - 0.5 * N_{YX}$$

The wave velocity values (c1 through c3) are related to the type of anchoring of the pipeline system (constant f1 through f3)

9 BURIED PIPES SYSTEM DESIGN

9.1 DESIGN PHILOSOPHY

Rational and experimental methods used in designing GRP/GRV systems are followed for AQAP pipes design. Most of performance limits are determined from long-term strength characteristics. Design factors are used to ensure adequate system over the intended system life of the pipe by providing for unforeseen variations in materials properties and loads.

The structural design procedure involves establishing of the design conditions, selection of the pipe classes and corresponding pipe properties, selection of installation parameters, and performing pertinent calculations to satisfy the design requirements. The procedure usually requires iterative calculation that can be simplified with the aid of the computer.

9.2 DESIGN AND JOINING SYSTEMS

When using AQAP pipe systems for underground applications, several types of joints can be used. In contrast to aboveground pipelines, the joints of underground systems can be unrestrained.

Only at directional changes and depending on the internal pressure, inner diameter and soil conditions, some lengths of pipes should be installed with tensile resistant couplers. Alternatively an external axial restraint, e.g. a concrete anchor block, can be used.

9.3 PIPE RESTRAINED LENGTH (VIRTUAL ANCHOR LENGTH)

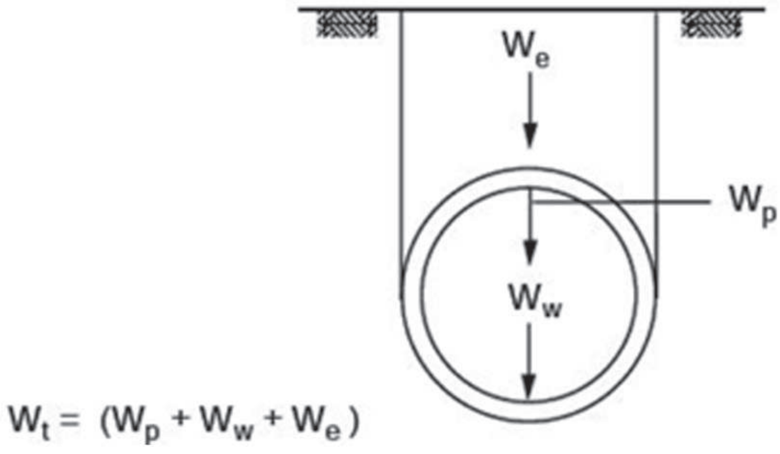
Buried un-restrained AQAP pipeline systems can be provided with thurst blocks at bends, reducers and branches. However, in some circumstances where long pipeline and fewer fittings are used, there is an option to remove the thrust blocks be considering a certain length of pipe section which is using a restrained joint (e.g., laminated joint, rubber seal lock joint or adhesive bonded joint), may offer a better solution.

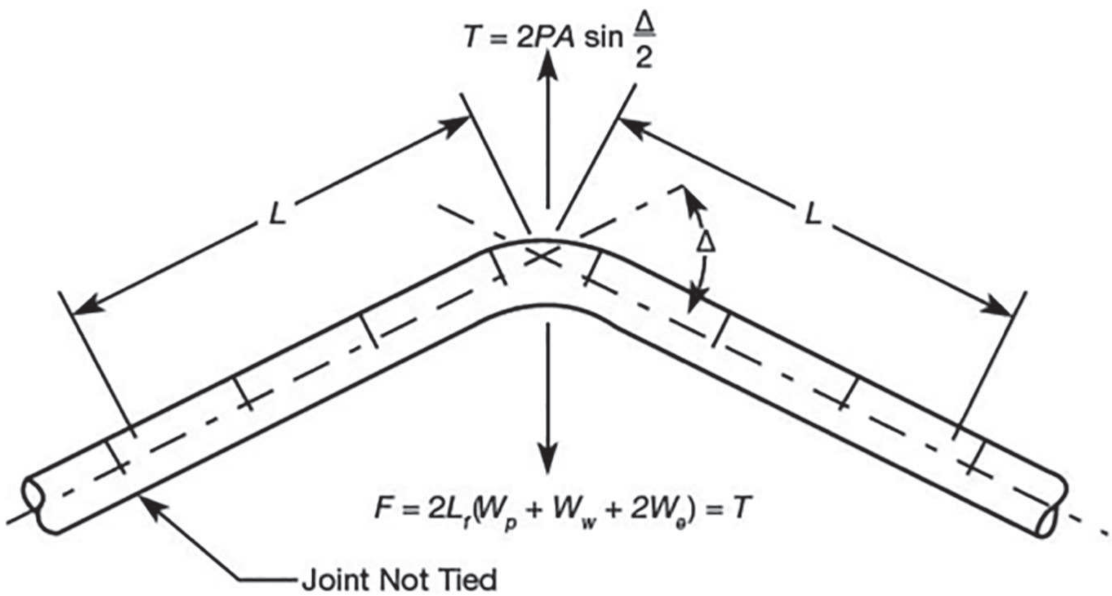
For this purpose, the restrained length L must be determined based on AWWA M45 Section 7. The restrained length L can be calculated from the following formula:

$$L_{bend} = \frac{PA\sin\left(\frac{\theta}{2}\right)}{f(2We+Wp+Ww)}$$

L_{bend} : Pipe Restrained length

P : Operating pressure or Testing Pressure
A : Pipe internal area
f : friction factorV
We : soil weight
Wp : pipe weight
Ww : fluid weight



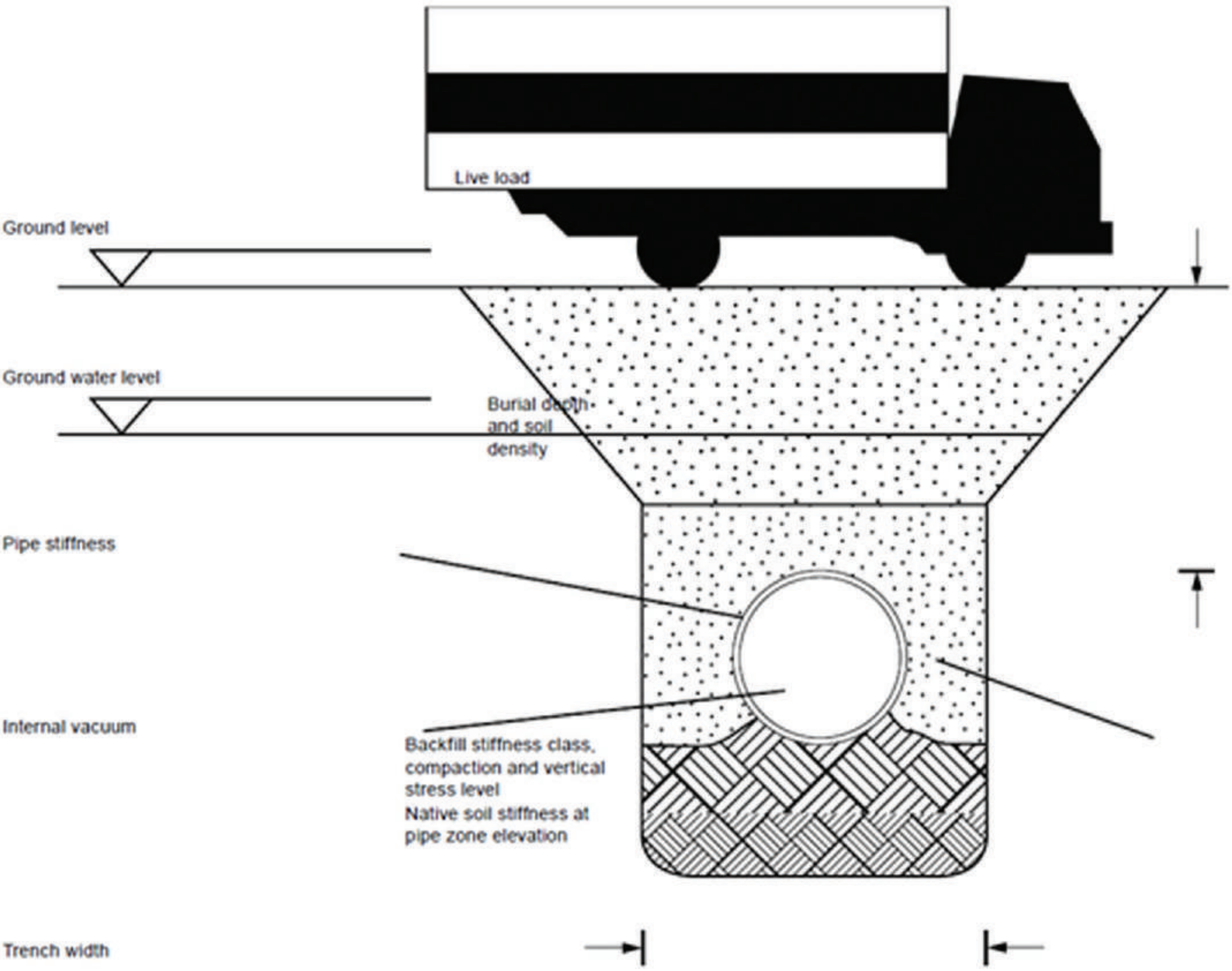


likewise, forces for other fittings Tees and reducers can be calculated considering the same concept of F (friction force) = T (Thrust force). Care must be taken considering a pipe hydro test case, which assumes a higher pressure and shallow depth.

9.4 CALCULATION OF UNDERGROUND PIPE SYSTEMS

Calculation of pipe deformation and data given in this section of the Engineering Guide is in line with AWWA Manual M45. Based on specific material data and many knowledgeable years of experience, this Engineering Guide may deviate from the AWWA Manual.

The stresses on the wall of a buried flexible pipe depend on the internal pressure and deflection due to external loads. The stress resulting from deflection is determined by the interaction between the soil and the pipe, which is, amongst other factors, directly related to the installation method.

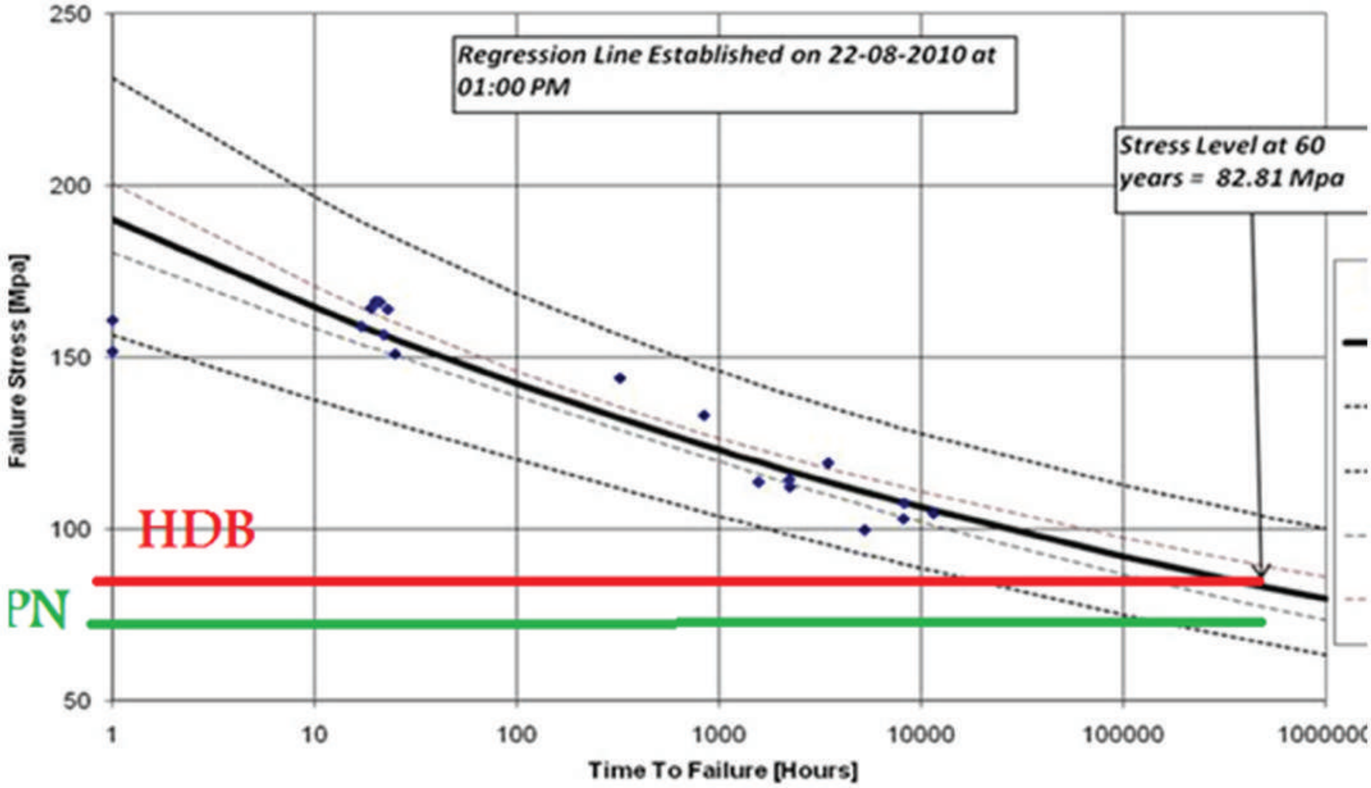


Input required for buried pipe calculation

- Pipe Diameter DN
- Working Pressure Pw
- Pressure Class PN
- Surge Pressure Ps
- Native soil data (Geotechnical report)
- Surround soil data (Bedding, side, and top)
- Groundwater level
- Min and Max soil depths
- Soil specific weight
- Vehicle traffic load
- Internal Vacuum Pressure
- Pipe Properties:
    - Pipe wall thickness
    - Long Term Hydrostatic Design Basis HDB
    - Hoop Tensile Modulus Eh
    - Ring Flexural Modulus Ehf
    - Pipe Stiffness class SN
    - Long Term Ring Bending Strain or Strain Corrosion Sb

$$P_c < \left(\frac{HDB}{FS}\right)\left(\frac{2t}{D}\right) * 10^3$$

$$P_c < \left(\frac{HDB}{FS}\right)\left(\frac{2tE_H}{D}\right) * 10^6$$



$$P_c \geq P_w$$

P_w : working pressure, kPa

$$P_c \geq \frac{(P_W + P_S)}{1.4}$$

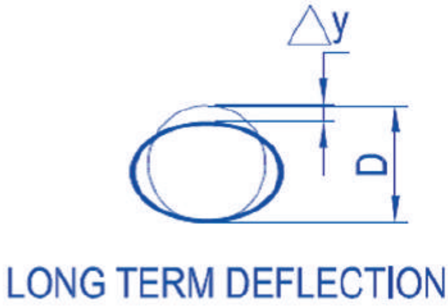
P_s : surge pressure, kPa

INTERNAL PRESSURE

Deflection

$$\frac{\Delta y}{D} < \frac{\delta d}{D} < \frac{\Delta y_a}{D}$$

- Burial depth
- Compaction
- Soil type
- etc



$\frac{\Delta y}{D}$ Calculated

$\frac{\delta d}{D}$ Permitted

$\frac{\Delta y_a}{D}$ Allowable

Allowable Deflection $\frac{\Delta ya}{D}$

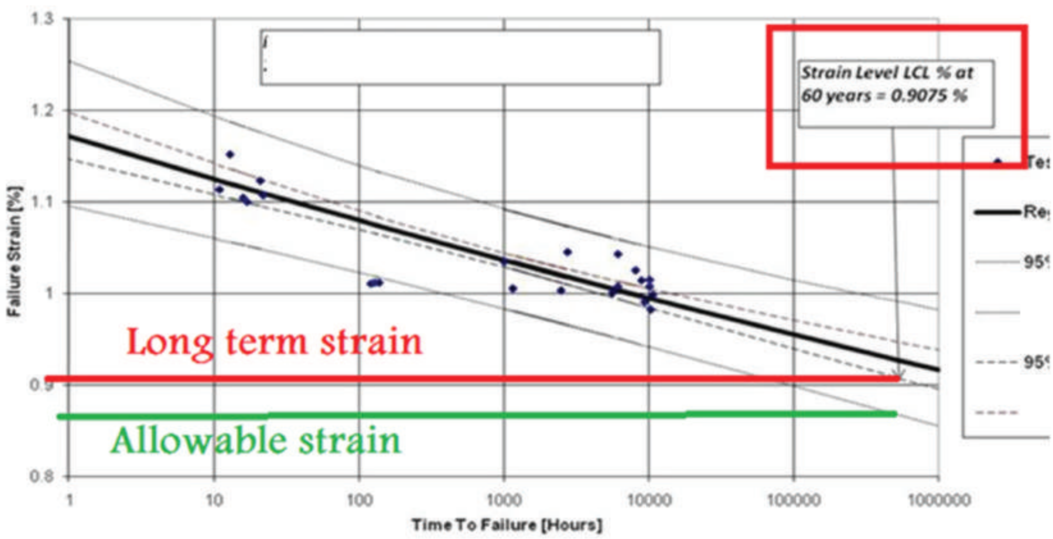
$$\sigma_b = 10^3 D_f E \left(\frac{\Delta y_a}{D}\right)\left(\frac{t_t}{D}\right) \le 10^3 \frac{S_b E}{FS}$$

$$\varepsilon_b = D_f \left(\frac{\Delta y_a}{D}\right)\left(\frac{t_t}{D}\right) \le \frac{S_b}{FS}$$

σ_b	:	ring-bending stress due to deflection, MPa
D_f	:	shape factor, dimensionless
E	:	ring flexural modulus of elasticity for the pipe, Gpa
Δy_a	:	limiting vertical pipe deflection, mm
S_b	:	long-term ring-bending strain for the pipe, mm/mm
D	:	mean pipe diameter, mm
FS	:	design factor, 1.5
ε_b	:	rind-bending strain due to deflection, mm/mm

Allowable Deflection $\frac{\Delta ya}{D}$. Should be extracted from long term allowable strain

S_b=extracted from long term strain corrosion test ASTM D3681



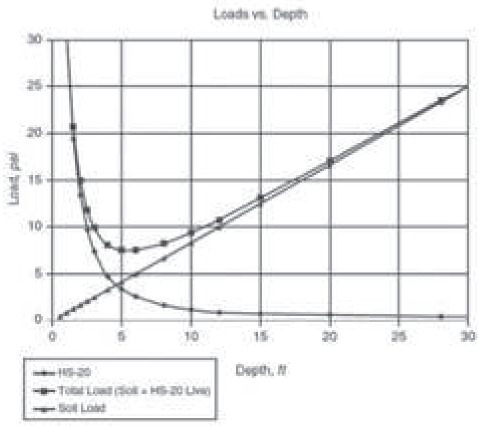
Permitted allowable $\frac{\delta_d}{D}$

Max normally permitted 5% $\frac{\Delta y_a}{D}$

Deflection

$$\frac{\Delta y}{D} < \frac{\delta_d}{D} < \frac{\Delta y_a}{D}$$

$$\frac{\Delta y}{D} = \frac{(D_L\, W_c + W_L) K_x}{149\ PS + 61{,}000\ M_s}$$



AASHTO HS-20 live load, soil load (120 lb/ft³), and total load graph

D_L : deflection lag factor, dimensionless
W_c : vertical soil load on pipe, N/m²
W_L : live load on pipe, N/m²
K_x : bedding coefficient, dimensionless
PS : pipe stiffness, kPa
M_s : composite soil constrained modulus, MPa

9.5 DEFLECTION LAG FACTOR

The deflection lag factor (D_L) converts the immediate deflection of the pipe to the deflection of the pipe after many years. For long term deflection prediction, a D_L-value greater than 1.00 is appropriate according to the AWWA Manual M45. We advise using a conservative value of D_L=1.5.

9.6 VERTICAL SOIL LOAD

The long term vertical soil load (W_C) can be considered as the weight of the rectangular prism of soil directly above the pipe. The soil load is calculated according to the equation W_C.

$$W_C = \gamma_s * H$$

W_C : Vertical soil load
γ_s : Unit weight of soil above the pipe
H : Burial depth to the top of the pipe

9.7 LIVE LOAD

The following calculations may be used to compute the life load on the pipe for surface traffic.
The calculations consider a single-axle truck travelling perpendicular to the pipe on an unpaved surface or a flexible pavement road.

$$W_L = \frac{M_P * P_W * I_f}{L_1 * L_2}$$

W_L : Life load on the pipe
M_P : Multiple presence factor
P_W : Wheel load
I_f : Impact factor
L_l : Load width parallel to the direction of travel
L_2 : Load width perpendicular to the direction of travel

Note: M_P : Factor resulting in acceptably conservation load estimates
M_P : 1.2 (-)

Tab 11 – Wheel load (P_W)

Identification	Wheel load (N)
VOSB 30	50,000
VOSB 45	75,000
VOSB 60	100,000
AASHTO HS-20	71,300
AASHTO HS-25	89,000
LKW 12	40,000
SKW 30	50,000
SKW 60	100,000

$$I_f = 1 + 0.33\left[\frac{(2.44 - H)}{2.44}\right] \geq 1.0$$

I_f : Impact factor
H : Burial depth to the top of the pipe

$$L_1 = t_l + LLDF * H$$

L1 : Load width parallel to the direction of travel
t_l : Length of the tire footprint
LLDF : Factor to account for life load distribution with the depth of fill
H : Burial depth to the top of the pipe.

Note: t_l : 0.25 m

Note: LLDF : Factor depending on Soil Stiffness Category (SC)

LLDF : 1.15 for SC1 and SC2
LLDF : 1.0 for all other backfills

If:

$$H \leq H_{int}$$

Then:

$$L_2 = t_w + LLDF * H$$

Else:

$$L_2 = (t_w + 1.83 + LLDF * H)/2$$

H : Burial depth to the top of the pipe
H_{int} : Depth at which load from wheels interacts
L_2 : Load width perpendicular to the direction of travel
t_w : Width of fire footprint
LLDF : Factor to account for life load distribution with the depth of fill.

Note: t_w : 0.5 m

H_{int}= (1.83-t_w)/LLDF

• **Life load reduction ratio**
The above calculation assumes that the life load (W_L) extends over the full diameter of the pipe. This may be conservation for large diameter pipe under low fills, where L_1 and L_2 OD.

To account for this, the calculated life load pressure on the pipe may be reduced by multiplying this life load pressure with a reduction ratio. The reduction ratio depends on the truck travel direction relative to the longitudinal axis of the buried pipe, as follow:

Tab 12 – Reduction ratio life load

Truck movement	Reduction ratio (m/m)
Across the pipe	L_1/OD
Parallel to the pipe	L_2/OD

• **Tandem-axle correction**
The previous calculation is valid for single-axis trucks. If both axles of a tandem-axle truckload the pipe at the same time, the load width parallel to the direction of travel L_1 should be substituted as shown below equation.

$$L_1 = (axle\ spacing + t_l + LLDF * H)/2$$

Tab 13 – Soil stiffness categories and Modulus of soil reaction

Soil Stiffness Category	Soil Types backfill material	Modulus of soil reaction (E') for degree of compaction (Mpa)			
		Dumped	Slight	Moderate	High
SC1	Crushed rock: ≤15% sand, maximum 25% passing the 10 mm sieve and maximum 5% passing No. 200 sieve.	6.9	20.7		
SC2	Clean, coarse-grainted soils: SW, SP, GW, GP, or any soil beginning with one of these symbols with 12% or less passing No. 200 sieve.	1.4	6.9	13.8	20.7
SC3	Coarse-grainted soils: GM, GC, SM, SC, or any soil beginning with one of these symbols with more than 12% fines. Sandy or gravely fine grainted soils: CL, ML (or CL-ML, CL/ML, ML/CL) with more than 30% retained on a No. 200 seive.	0.69	2.8	6.9	13.8
SC4	Fine-grainted soils: CL, ML (or CL-ML, CL/ML, ML/CL) with 30% or less retained on a No. 200 sieve.	0.34	1.4	2.8	6.9
SC5	Highly plastic and organic soils: MH, CH, OL, OH, PT.	Not suitable for use as backfill for flexible pipe			

In line with ASTM D2487, Practice for classification of soils for engineering purposes; see table 13.

Slight	= < SPD85/	relative density < 40%
Moderate	= SPD85 < SPD95 / 40%<	relative density < 70%
High	= > SPD95/	> 70% relative density
SPD	= Standard Proctor Density	

Tab 14 – Soil classification

Group Symbol	Group Name
GW	Well graded gravels, gravel-sand mixtures, little or no fines
GP	Poorly graded gravels, gravel-sand mixtures, little or not fines
GM	Silt gravels, poorly graded gravel-sand-slit mixtures
GC	Clayey gravels, poorly graded gravel-sand-clay mixtures
SW	Well graded sands, gravely sands, little or no fines
SP	Poorly graded sands, gravely sands, little or no fines
SM	Slit sands, poorly graded sand-silt mixtures
SC	Clayey sands, poorly graded sand-clay mixtures
ML	Inorganic silts and very find sand, salty or clayey fine sands
CL	Inorganic clays of low to medium plasticity
MH	Inorganic silts, micaceous or diatomaceous fine sandy or silt soils, elastic silts
CH	Inorganic clays of high plasticity, fat clays

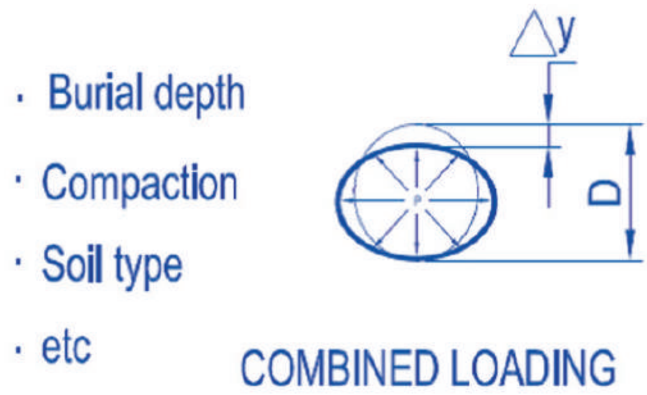
Combined loading

$$\frac{\sigma_{pr}\, FS_{pr}}{HDB} + \frac{\sigma_b\, r_c}{S_b E * 10^3} \leq 1$$

$$\frac{\sigma_b\, r_c\, FS_b}{S_b E * 10^3} + \frac{\sigma_{pr}}{HDB} \leq 1$$

$$\frac{\varepsilon_{pr} FS_{pr}}{HDB} + \frac{\varepsilon_b r_c}{S_b} \leq 1$$

$$\frac{\varepsilon_b r_c FS_b}{S_b} + \frac{\varepsilon_{pr}}{HDB} \leq 1$$



FS_{pr} : pressure design factor, 1.8

FS_b : bending design factor, 1.5

σ_{pr} : hoop stress due to internal working pressure, MPa

$$\frac{P_w D}{2t}$$

σ_b : bending stress due to the maximum permitted deflection, MPa

$$10^3 D_f E \left(\frac{\delta d}{D}\right)\left(\frac{t_t}{D}\right)$$

r_c : rerounding coefficient, dimensionless

$$1 - \frac{P_w}{3{,}000}\ (\text{where } P_w \leq 3{,}000\ \text{kPa})$$

ε_{pr} : hoop strain due to internal working pressure, mm/mm

$$\frac{P_w D}{2t E_H}$$

ε_b : bending strain due to the maximum permitted deflection, mm/mm

$$D_f \left(\frac{\delta d}{D}\right)\left(\frac{t_t}{D}\right)$$

δd : maximum permitted long-term installed deflection, mm

Buckling load

q_a : allowable buckling load

$$q_a = \frac{(1.2C_n)(EI)^{0.33}(\varphi_s 10^6 M_s k_v)^{0.67} R_h}{(FS)r}$$

q_a : allowable buckling pressure, kPa

FS : design factor, 2.5

C_n : scalar calibration factor to account for some nonlinear effects = 0.55

φ_s : factor to account for variability in Stiffness of compacted soil, suggested value is 0.9

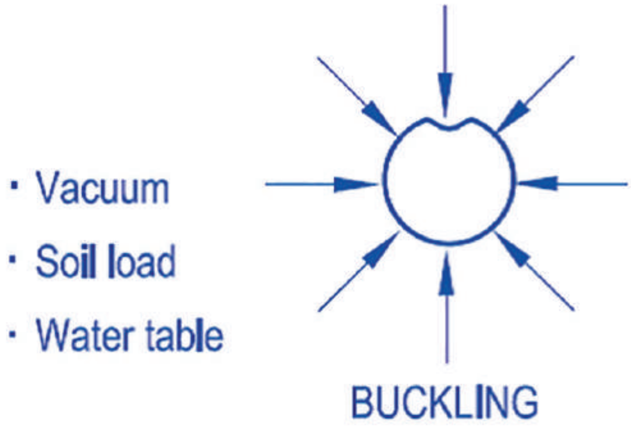
k_v : modulus correction factor for Poisson's ratio, v, of the soil

: (1+v)(1-2v) / (1-v), in the absence of specific information, it is common to assume v=0.3 giving k_v=0.74

R_h : correction factor for depth of fill

: 11.4 /(11+D/1,000 h)

h : height of the ground surface above the top of the pipe, m



Water Table Soil Weight Vacuum

$$[\gamma_w h_w + R_w(W_c)] * 10^{-3} + P_v \leq q_a$$

Water Table Soil Traffic

$$[\gamma_w h_w + R_w(W_c) + W_L] * 10^{-3} \leq q_a$$

Special Design Consideration:

- Elevated temperature service
- Broad temperature fluctuations.
- Shallow burial, where H<2 ft (0.6m).
- Uneven bedding or differential settlement of unstable native soils.
- Restrained tension joints.
- Challenging construction conditions (for example, subaqueous installation).
- Unusually high surface or construction loads (live load)

10 OTHER CONSIDERATION

10.1 EARTHQUAKE

Earthquake exerts its action on the three space directions. However, only two of them (vertical and parallel directions to the pipeline) have practical effects.

Vertical Action
Earthquake action is converted into an increased gravity acceleration value, which means a higher soil load on the pipeline and a shear action on the pipe.

Parallel Action
Soil movement along the pipeline determines (because of the friction between soil and pipeline) the sliding of pipeline joints if they are bell and spigot double O-ring type, or axial stress if joints are bell and spigot double O-ring key lock type.
Earthquake action along the direction normal to pipeline and parallel to the ground is negligible.

Seismic acceleration calculation
Vertical and horizontal accelerations due to earthquake are calculated as follows:

$$a_v = m\,C\,I\,g$$
$$a_h = R\,C\,I\,g$$

a_v : Vertical acceleration, m/s^2
a_h : Horizontal acceleration, m/s^2
m : Dimensionless coefficient, usually = 2
C : Seismic intensity coefficient = (S-2)/100
I : Seismic protection coefficient, usually = 1.2
R : Response coefficient of structure
g : Gravity acceleration, 9.81 m/s^2
S : Seismic grade (S>=2), usually = 9

R (response coefficient) is assumed as a function of the fundamental period T_o of the structure, for oscillations along the considered direction:

when T_o>0.8 s R=0.862/$T_o^{0.667}$

when T_o<=0.8 s R=1

In the case of indetermination of T_o a value of R equal to 1 (maximum value) shall be assumed.
The respective vertical and horizontal accelerations due to the earthquake are:

$$a_v = 2 * (9-2)/100 * 1.2 * g = 0.17\,g = 1.65\,m/s^2$$

$$a_h = 1 * (9-2)/100 * 1.2 * g = 0.084\,g = 0.82\,m/s^2$$

Accelerations during earthquake shall be:

Vertical action

$$a_v + g = 1.17\ g = 11.5\ m/s^2$$

Horizontal action

$$a_v = 0.08\ g = 0.82\ m/s^2$$

Check of pipe buckling during an earthquake
Vertical action increases the weights of the ground and the live load operating on the pipeline. This condition determines a reduction of the safety factor to buckling.

Buckling is checked at the depth predicted by the design through the following formula (AWWA C950-88)

$$q_a = (1/FS)(32\ R_w B'\ E'\ S)^{½}$$

$$q_{ex} = \left(R_w \frac{W_C}{D} + \frac{W_L}{D}\right)\frac{a_v + g}{g} \qquad q_{ex} = \text{external loads, N/mm}^2$$

$$q_a / q_{ex} \geq 1$$

10.1.1 SEISMIC STRAIN OF GROUND

To calculate the seismic action along the direction parallel to the pipe, it is necessary to consider the strain of ground during an earthquake:

$$\varepsilon_g = (T_g a_h)/(2v_s)$$

T_g : Seismic wave period, s
a_h : Horizontal acceleration, m/s²
v_s : Propagation speed of the seismic wave, m/s

11 SYSTEM DESIGN FOR SELF RESTRAINED SYSTEM (AG AND UG):

The self-restrained piping system design is called Stress Analysis of a piping system, usually done using specialized software with some additional manual calculation. The stress evaluation will be computed using Either ASME B31.3 code or ISO 14692 code. Other codes also may be applicable but not commonly used.

The overall stress, which is equivalent to the sun of the axial stresses, shall be defined by the following formula:

$$\sigma_{a,sum} = \sigma_{ap} \pm \sigma_{ab} + \sigma_{af} \pm \sigma_{ac} + \sigma_{at}$$

$$\sigma_{ap} = \frac{P * D_{r,min}}{4 * t_{r,min}}$$

For a closed, unrestrained pip

$$\sigma_{ap} = v_{ah} * \frac{P * D_{r,min}}{2 * t_{r,min}}$$

For an axially restrained pipe

$$\sigma_{ab} = 1000 * \frac{\sqrt{(SIF_{ai} * M_i)^2 + (SIF_{ao} * M_o)^2}}{Z_r}$$

$$Z_r = \frac{\pi}{32} * \frac{\left(OD_{r,min}^4 - ID_r^4\right)}{OD_{r,min}}$$

$$\sigma_{af} = \frac{F_a}{A_r} = \frac{F_a}{\frac{\pi}{4} * \left(OD_{r,min}^2 - ID_r^2\right)}$$

$$\sigma_{ac} = \frac{OD_{r,min}}{2 * C * 1000} * E_a$$

$$\sigma_{at} = \alpha_a * \left(T_{install} - T_{design}\right) * E_a$$

P	:	is the internal pressure, expressed in MPa
ID_r	:	is the inside diameter of the reinforced pipe wall, expressed in mm
$OD_{r,min}$	:	is the minimum outside diameter of the reinforced pipe wall expressed in mm
σ_{ap}	:	is the axial stress from internal pressure, expressed in MPa
v_{ah}	:	is the minor Poisson's ratio, hoop strain resulting from stress in the axial direction
SIF_{ai}	:	is the axial in-plane stress intensification factor
SIF_{ao}	:	is the axial out-of-plane stress intensification factor
M_i	:	is the in-plane bending moment, expressed in Nm
M_o	:	is the out-plane bending moment, expressed in Nm
Z_r	:	is the minimum reinforced pipe wall section modulus, expressed in mm^3
F_a	:	is the localized axial force, expressed in N
A_r	:	is the minimum reinforced pipe wall cross-section, expressed in mm^2
C	:	is the curve radius, expressed in m
E_a	:	is the axial tensile modulus, expressed in MPa
α_a	:	is the coefficient of thermal expansion in the axial direction, expressed in mm/mm/°C
$T_{install}$	:	is the installation temperature, expressed in °C
T_{design}	:	is the design temperature, expressed in °C

Note: σ_at only occurs in piping systems where axial growth is restrained. In other configurations (such as in an expansion loop or direction change), thermal growth can create reaction forces and moments which need to be adequately analyzed.

Note: Temperature changes are assumed to produce no hoop stress component.

Note: Piping subject to internal pressure will be treated as unrestrained pipes, which will grow axially with increasing pressure, plus an axial lend load, which, for a fully restrained system, will return the pipe to its original length (i.e., no length change for a fully restrained system). This method will provide a consistent approach for analyzing unrestrained, anchored, and buried piping systems. Similarly, piping subject to temperature changes will be treated as unrestrained pipes. Such pipes grow axially with increasing temperature, plus an axial end load, which will return the pipe to its original length for a fully restrained system. Temperature changes are assumed to produce no hoop stress component.

Note: Restrained piping is assumed to be restrained in the axial direction only; there is no restraint in the hoop direction. In long-buried piping, the axial friction forces accumulate to prevent axial movement. But, in the hoop direction, the typical soil elastic modulus is much lower than the pipe hoop modulus and is ineffective in restraining the pipe. Consequently, the calculated hoop stress from internal pressure for both unrestrained and restrained pipes is the same. However, the calculated axial stress from internal pressure includes the Poisson's effect for restrained pipes only. One exception to this rule may be piping encased in concrete where the internal pressure cannot generate hoop stress. In this exception, the assumption regarding directional restraint would produce a conservative design and should remain safe.

Note: σ_{at} can be considered a form of σ_{af}, taking care that these stresses are twice not applied. σ_{at} is intended to be applied to fully-restrained piping systems (either above-ground or buried)

The term σ_ab will typically include both tensile and compressive stresses on opposite sides of the pipe. These sides may be the top/bottom or the left/right sides. Consequently, it shall be necessary to sum the stresses (taking note of whether each stress is positive or negative) in each plane properly and determine a vector sum of the two totals according to the formula below:

$$\sigma_{a,sum} = \sigma_{ap} + \sqrt{\left(\Sigma\sigma_{ab,top/bottom}\right)^2 + \left(\Sigma\sigma_{ab,left/right}\right)^2} + \sigma_{af} \pm \sigma_{ac} + \sigma_{at}$$

Note: For above-ground cross country pipelines, both σ_{ac} (roping curvature) and σ_{ab} (free span bending) can be present in both planes at some locations and thus require the resulting stresses to be determined by proper vector-summation.

Note: The reference to restrained and unrestrained in the guidance above is not referring to the type of joint (e.g. a laminated or adhesively bonded joint is a restrained joint). Rather, it is referring to the type of installation for the system.

The sum of the hoop stresses and the sum of the axial stresses shall be within the design envelope for each loading case.

11.1 SHELL BUCKLING

The axial elastic buckling stress, σ_(u,s), in MPa, for a cylinder in pure bending shall be taken as:

$$\sigma_{u,s} = 0.90 * \beta * \frac{E_a * t_{r,min}}{D_{r,min}}$$

E_a : is the axial tensile modulus, expressed in MPa

$t_{r,min}$: is the maximum reinforced pipe wall thickness, expressed in mm

$D_{r,min}$: is the mean diameter of the minimum reinforced pipe wall, expressed in mm

The value β is obtained from the formula below:

$$\beta = 0{,}188\,7 + 0{,}811\,3 * \beta_0$$

The value β_0 is obtained from the formula below:

$$\beta_0 = \frac{0{,}83}{\sqrt{0{,}1+0{,}005*\left(\frac{ID_r}{t_{r,min}}\right)}}$$

The ratio of the axial elastic buckling stress to σ_ab shall be greater than or equal to 3:

$$\frac{\sigma_{u,s}}{\sigma_{ab}} \geq 3{,}0$$

Note: Shell buckling is primarily an issue for the thin-walled large-diameter pipe.

11.2 EULER BUCKLING

For axial compressive system loads, e.g., constrained thermal expansion or vertical pipe rums with end compressive loads, and given length of unsupported pipe, *L*, the axial compressive load shall not exceed $F_{a,max}$, in N, defined using the below formula:

$$F_{a,max} = \frac{\pi^2 * l_r}{L^2} * E_a * 10^6$$

I_r : is the minimum reinforced pipe wall moment of inertia, expressed in mm^4

L : is the length of the unsupported pipe, expressed in m

E_a : is the axial tensile modulus, expressed in MPa

Note: Both ends of the pipe are assumed to be pinned or free to rotate. If the ends of the pipe are fixed or anchored, the value of $F_{a,max}$ increases by a factor of 4.

The equivalent Euler buckling stress, in MPa, is given by the formula below:

$$\sigma_{u,e} = \frac{F_{a,max}}{A_r}$$

$F_{a,max}$: is the maximum axial compressive load, expressed in N
A_r : is the minimum reinforced pipe wall cross-section, expressed in mm^2

The ratio of the equivalent Euler buckling stress to the maximum compressive stress shall be greater than or equal to 3:

$$\frac{\sigma_{u,e}}{\sigma_{a,comp}} \geq 3{,}0$$

$\sigma_{u,e}$: is the equivalent Euler buckling stress, expressed in MPa
$\sigma_{a,comp}$: is the maximum compressive stress on the unsupported length of piping, expressed in MPa

Note: σ_{ap}, σ_{af}, σ_{at} can have axial compressive stress components that are due to axial compressive system loads. Only compressive loads are considered when evaluating Euler buckling.

Note: The designer may also need to consider Euler buckling from internal pressure (i.e. the water column causes the buckling). Theoretically, this buckling pressure is equal to the pressure that provides a “virtual” axial pressure thrust load equal to the Euler column buckling load. This phenomenon can occur in small bore above-ground piping systems.

11.3 UPHEAVAL BUCKLING PRESSURE

Upheaval buckling is a common design issue for buried pipelines operating at high temperatures and/or high pressure. When the high axial compressive forces are imposed on the pipeline due to the operating conditions, the pipeline tends to buckle upwards. To prevent upheaval buckling, the pipeline shall be buried deep enough so that the soil cover provides sufficient resistance to the upheaval forces.

The designer shall consider acceptable practices to design for upheaval buckling in buried pipelines.

11.4 LONGITUDINAL PRESSURE EXPANSION

The strain from longitudinal pressure expansion in an unrestrained piping system, $\varepsilon_{p,avg}$, commonly referred to as “Poisson’s effect”, can be determined with the formula below:

$$\varepsilon_{ap,avg} = \frac{\sigma_{ap,avg}}{E_a} - \upsilon_{ha} * \frac{\sigma_{hp,avg}}{E_h}$$

Where $\sigma_{hp,avg}$ is calculated differently with the formula below:

$$\sigma_{hp,avg} = \frac{P * ID_r}{2 * t_{r,min}}$$

And $\sigma_{ap,avg}$ is calculated differently with the formula below:

$$\sigma_{ap,avg} = \frac{P * ID_r^2}{OD_{r,min}^2 - ID_r^2}$$

Note: Elastic response is associated with the average stress in the pipe wall.

12 ABOVE GROUND PIPE SYSTEM DESIGN METHODOLOGY AND SUPPORT DESIGN

12.1 RESTRAINED SYSTEM DESIGN

The restrained system is often referred to as an "anchored and guided design". The low modulus of elasticity for fiberglass piping translates to significantly smaller thermal forces when compared to steel. Anchors are employed to restrain axial movement and provide vertical support in horizontal pipelines. Anchors used to restrain thermal expansion create compressive forces in the pipeline. These forces must be controlled by the use of pipe guides to prevent the pipe from buckling. In cases where axial loads created by anchoring a pipe run are excessively high, the use of expansion loops or expansion joints must be employed. When using anchors, the effect of system contraction should be considered. See the thermal analysis section for more thorough information on handling thermal loads.

The properly designed piping system provides safe and efficient long-term performance under varying thermal environments. The system design dictates how a piping system will react to changes in operating temperatures. The unrestrained piping system undergoes expansion and contraction in proportion to changes in the pipe wall mean temperature. Fiberglass piping systems that operate at or near the installation temperature are normally unrestrained designs, where the most important design consideration is the basic support span spacing. Since few piping systems operate under these conditions, some provisions must be made for thermal expansion and contraction.

The simplest unrestrained piping systems use directional changes to provide flexibility to compensate for thermal movements. When directional changes are unavailable or provide insufficient flexibility, the use of expansion loops or expansion joints should be designed into the system to prevent overstressing the piping system. These systems are considered unrestrained even though partial anchoring and guiding of the pipe is required for proper expansion joint, expansion loop performance and system stability.

The fully restrained “anchored” piping system eliminates axial thermal movement. Pipe and fittings generally benefit from reduced bending stresses at directional changes. Restrained systems develop internal loads required to maintain equilibrium at the anchors due to temperature changes. When the pipe is in compression, these internal loads require guided supports to keep the pipe straight preventing Euler buckling. Thus, the commonly referred to name of restrained systems is “anchored and guided”. Anchored and guided systems have anchors at the ends of straight runs that protect fittings from thermal movement and stresses.

Anchors at directional changes (elbows and tees) transmit loads to the support substructure. Special attention should be given to these loads by the piping engineer to ensure an adequate substructure design. When multiple anchors are used to break up long straight runs, the loads between them and the substructure are generally small. The axial restraining loads are simply balanced between the two opposing sides of the pipeline at the anchor.

THERMAL PROPERTIES & CHARACTERISTICS

The reaction of fiberglass piping to changes in temperature depends on two basic material properties, the thermal “coefficient of expansion”(a) and the axial moduli of elasticity. The composite nature of fiberglass piping results in two distinctive axial moduli of elasticity. They are the axial compression and axial tensile moduli. Systems installed at ambient temperature and operated at higher temperatures will generate internal compression piping stress when anchored. Although this is the most common engineering design condition, the piping engineer should not overlook the opposite thermal condition that generates tensile stresses.

The thermal properties of fiberglass pipe distinguish it from steel in important ways. The coefficient of expansion is roughly twice that of steel. This translates to twice the thermal movement of steel in unrestrained systems. The axial compression modulus of elasticity of fiberglass pipe varies from 3% to 10% that of steel. When restraining thermal movements in fiberglass piping the anchor loads would be 1/5 or less than the loads created by a same size and wall thickness in steel piping system.

Thermoplastic pipe coefficients of expansion are typically more than four times that of fiberglass. The elastic modulus of thermoplastic piping is considerably smaller than the moduli of fiberglass and steel. The modulus of elasticity of thermoplastic pipe decreases rapidly as the temperatures increases above 100°F. This results in very short support spans at elevated temperatures. A restrained thermoplastic piping system operating at elevated temperatures is very susceptible to buckling thus requiring extensive guiding.

It is important to properly determine the temperature gradient. The gradient should be based on the pipeline temperature at the time that the system is tied down or anchored. If the operating temperature is above this temperature, then the gradient is positive and conversely if it is less than this temperature, then the gradient is negative. Many piping systems will see both positive and negative temperature gradients that must be considered during the system design.

FGS software Success By Design performs thermal analysis on fiberglass piping systems based on the methods discussed in this section. The benefits of using Success By Design are not only ease of use, but increased analysis accuracy. The software evaluates the fiberglass material properties at the actual operating temperatures, eliminating the conservatism built into charts and tables designed to cover worst case scenarios for all designs.

FUNDAMENTAL THERMAL ANALYSIS FORMULAS

A. Thermal Expansion and Contraction

The calculation of thermal expansion or contraction in straight pipelines is easily accomplished using the following equation.

Eq. (1)

$$\delta = \alpha * L * (T_o - T_i)$$

δ : Length change, in (m)
α : Thermal coefficient of expansion, in/in/°F (m/m/°C)
L : Pipe length, in (m)
T_o : Operating temperature, °F (°C)
T_i : Installation temperature, °F (°C) Final tie-in or completion temperature.
(T_o-T_i) is the temperature gradient

B. Anchor Restraint Load

The calculation of the restrained load in a pipeline be- tween two anchors is easily accomplished using the following equation.

Eq. (2)

$$F_r = \alpha * A * E * (T_o - T_i)$$

F_r : Restraining force, lb (N)
α : Thermal coefficient of expansion, in/in/°F (m/m/°C)
A : Reinforced pipe wall cross-sectional area, in² (m²)
T_o : Operating temperature, °F (°C)
T_i : Installation temperature, °F (°C) Final tie-in or completion temperature.
(T_o-T_i) is the temperature gradient
E : Axial modulus of elasticity, lb/in² (N/m²)

The compression modulus should be used with a positive temperature change (T_o>T_i) and the tensile modulus with a negative temperature change (T_o>T_i).

The reactions on the external support structure at internally spaced anchors in long straight runs are negligible because of the in-line forces balance. However, the anchors at the end of straight runs transmit the full load to the support structure.

C. Guide Spacing

The Guide spacing calculations are derived from Euler's critical elastic buckling equation for a slender column with pivot ends.

Eq. (3)

$$L_g = \sqrt{\frac{\pi^2 * E * I}{F_r}}$$

L_g : Guide spacing, in (m)
F_r : Restraining force, lb (N)
E : Bending modulus of elasticity, lb/in² (N/m²)
I : Pipe area moment of inertia, in⁴ (m⁴)
π : Pi – 3.14159

Flexibility Analysis and Design

There are four primary methods of controlling thermal expansion and contraction in above-ground piping systems. They are:

1. Anchoring and Guiding
2. Directional Changes
3. Expansion Loops
4. Mechanical Expansion Joints

The use of anchors and guides, as discussed earlier, depends on restraining thermal growth. Directional changes, expansion loops, and mechanical expansion joints use component flexibility to safely absorb thermal movements.

A. Directional Change Design

The flexibility analysis of a directional change is based on a guided cantilever beam model. The cantilever must be of sufficient length to ensure the pipe will not be overstressed while absorbing the thermal movement. This is accomplished by satisfying the following equations.
Based on pipe allowable bending stress.

Eq. (4)

$$L = \sqrt{\frac{K * \delta * E * OD}{\sigma}}$$

K	:	3, Guided cantilever beam coefficient
L	:	Length of cantilever leg, in (m)
E	:	Pipe beam bending modulus of elasticity, lb/in² (N/m²)
OD	:	Pipe outer diameter, in (m)
δ	:	Total deflection to be absorbed, in (m)
σ	:	Pipe allowable bending stress, lb/in² (N/m²)

Based on fitting allowable bending moment

Eq. (5)

$$L = \sqrt{\frac{K * E * I * \delta}{M}}$$

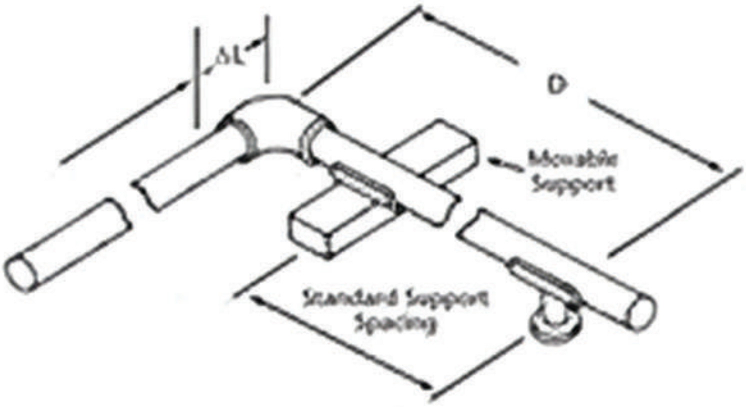
K	:	6, Guided cantilever beam coefficient
L	:	Length of cantilever leg, in (m)
E	:	Pipe beam bending modulus of elasticity, lb/in² (N/m²)
I	:	Pipe reinforced area moment of inertia, in⁴ (m⁴)
δ	:	Total deflection to be absorbed, in (m)
M	:	Fitting allowable bending moment, in-lb (N-m)

Minor out of plane rotation of the elbow should be allowed to minimize bending moments on the elbow. The use of the guided cantilever beam equation results in conservative leg lengths.

See Figure 12-1 for a typical horizontal directional change layout.

Figure 12-1

Horizontal Directional Change

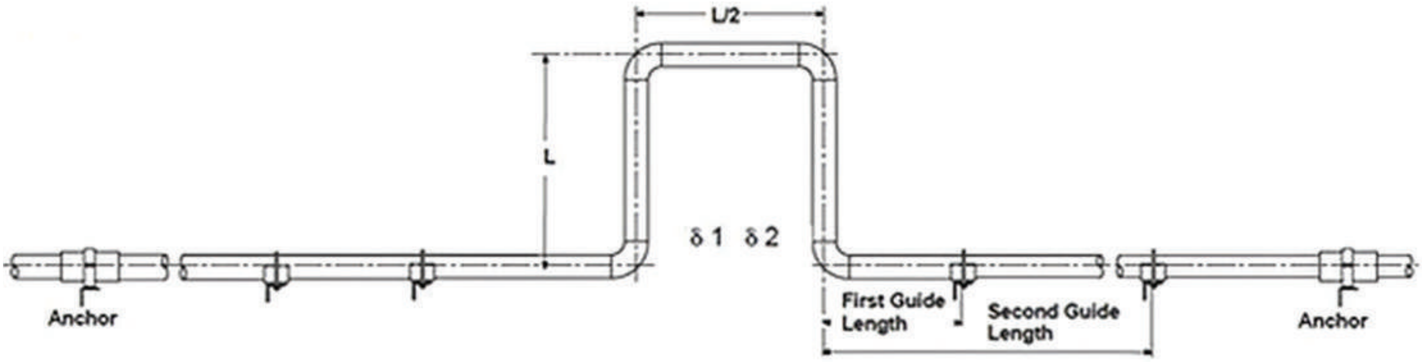


B. Expansion Loop Design

The flexibility of an expansion loop is modeled using two equal length guided cantilever beams. Each cantilever absorbs half of the thermal expansion or contraction. The cantilevers must be of sufficient length to ensure the pipe and fittings will not be overstressed. Establishing the minimum required lengths is accomplished by satisfying equation 4 with K= 1.5 and equation 23 with K=3.

These equations should be used with the total deflection (d=d1+d2) to be absorbed by both expansion loop legs. See Figure 12-2 for a typical expansion loop layout.

Figure 12-2



C. Expansion Joint Design

Mechanical expansion joint use requires the engineer to determine the complete range of thermal movement expected in the system. This is accomplished by calculating the maximum thermal expansion and thermal contraction for the operating conditions. The mechanical expansion joint must be capable of absorbing the full range of thermal movement with an appropriate margin of safety. During installation, the set position must be determined to ensure the expansion joint will accommodate the entire movement range. This is accomplished using the following equation.

Eq. (6)

$$SetPoint = R * Travel$$

SetPoint: Installed position of mechanical expansion joint “Distance from the joint being fully compressed”, in(m)
Travel : Mechanical expansion joint maximum movement, in(m)

Eq. (7)

$$R = \frac{T_i - T_{min}}{T_{max} - T_{min}}$$

R	:	Thermal ratio
T_i	:	Installation tie-in temperature, F°(C°)
T_{min}	:	Minimum operating temperature, F°(C°)
T_{max}	:	Maximum operating temperature, F°(C°)
$T_{min} \leq T_i$		

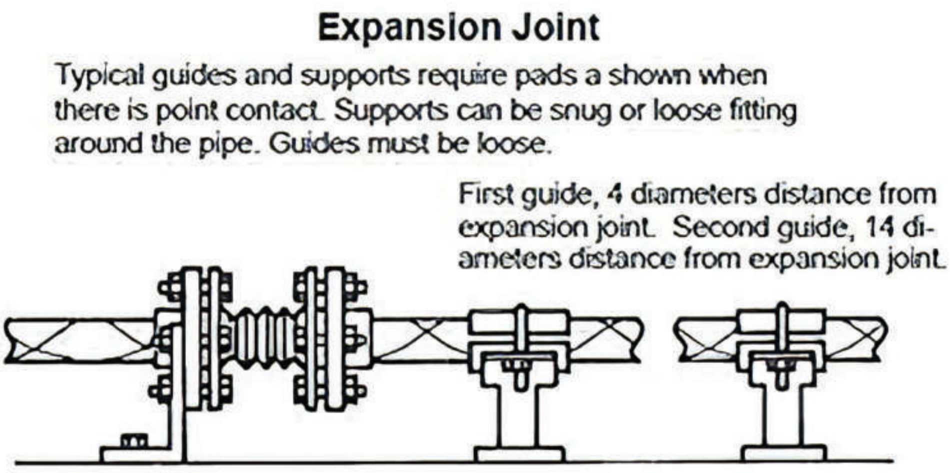
Example Problem:
Determine the “Travel” and “Set Point” for the following conditions.

T_i=75°F, T_{min} (23.9 C) =45°F, T_{max} (7.2 C) =145°F, R=0.3 (62.8 C)

Pipe total thermal movement is 6 inches.

Design factor 1.5

Figure 12-3



Expansion joint “Travel” required is 9 inches (6 x 1.5). The “Set Point” should be 0.3 x 9 = 2.7 inches (compression). This set point allows for 1.5 times the thermal growth or contraction for the given operating conditions. See Figure 12-3 for a typical expansion joint layout.

The proper selection of an expansion joint design depends on the piping system’s available activation forces. Equation 2 should be used to determine the fully restrained activation force capability of the piping system. If a mechanical expansion joint requires an activation force higher than the fully restrained activation force, then the expansion joint will not function. In practice, the expansion joint activation force should not exceed ¼ of the load in a fully restrained piping system. Mechanical expansion joint requiring higher activation forces may not provide sufficient flexibility to warrant its use.

It is prudent engineering practice to determine if the piping system will require guiding under the compression activation forces. Equation 3 should be used to determine the guide spacing.

D. Heat Tracing

Heat tracing is the practice of heating a piping system to prevent freezing or cooling a process line. Steam tracing and electrical heat tapes are typical methods of heat tracing fiberglass piping. The maximum heat tracing temperature is governed by one of three criteria:

(1) The mean wall temperature must not exceed the maximum temperature rating of the pipe,

Eq. (8)

$$\frac{T_{in}+T_{ra}}{2} \leq T_{pr}$$

(2) The maximum tracing element temperature must not exceed 100°F(55.6C°) above the temperature rating of the pipe.

Eq. (9)

$$T_{pr} + 100 \leq T_{ra}$$

(3) The maximum recommended temperature for the service chemical must not be exceeded at the surface of the pipe's inner wall.

Eq. (10)

$$T_{in} - T_{cr} \leq 0$$

For stagnant flow, the temperature of the pipe's fluid and inner surface can be assumed to equal the trace temperature. This assumption is valid if the heat trace element provides sufficient energy to overcome heat losses to the environment. For the stagnant or no flow condition, equation 29 is used to determine the maximum allowable heat trace temperature.

Eq. (11)

$$T_{in} = T_{cr}$$

Therefore:

Eq. (12)

$$T_{ra} = T_{cr}$$

For Eq. 8-12

- T_{in} : Pipe inner surface temperature, °F(°C)
- T_{ra} : Heat trace element temperature, °F(°C)
- T_{pr} : Pipe temperature rating, °F(°C)
- T_{cr} : Chemical resistance temperature rating of the pipe, °F(°C)

Determination of the pipe inner wall temperature under operational flow conditions depends on flow rate, the specific heat of the fluid, the temperature of the fluid entering pipe, conduction through the pipe wall, external environmental heat losses, and the heating element capacity. The complexity of this analysis is beyond the scope of this manual. Therefore, prudent engineering practices should be employed to determine the safe heat tracing temperatures under these conditions.

These criteria are most easily explained by the following examples:

Example: What is the maximum heat tracing temperature allowed to maintain a 5% caustic solution at 95°F (35 C) inside a Red Thread II pipe rated to 210°F (99 C)?

The three governing criteria must be considered to determine the maximum tracing element temperature.

Step 1: Solving for criterion (1) equation (8) is applied

$$T_{ra} \leq 2 * T_{pr} - T_{in}$$

$$T_{ra} \leq 2 * 210 - 95$$

$$T_{ra} \leq 325$$

Rearranging and solving for the maximum trace temperature, T_{ra} we get 325°F (162.8 C)

Step 2: Solving for criterion (2) equation (9) is applied

$$T_{ra} \leq T_{pr} + 100$$

$$T_{ra} \leq 210 + 100$$

$$T_{ra} \leq 310$$

Rearranging and solving for the maximum trace temperature, T_{ra} we get 310°F (37.8 C)

Step 3: Solving for criterion (2) equation (12) is applied

$$T_{ra} = T_{cl}$$

Therefore, the maximum allowable heat trace temperature equals the maximum chemical resistance temperature for the piping. Referencing Chemical Resistance Guide, Bulletin No. E5615, Red Thread II pipe is rated to 100°F in 5% caustic. Therefore, the maximum heat trace temperature is 100°F (37.8 C).

However, if the fluid were flowing into the pipeline at temperatures below 100°F (37.8 C), the heat trace temperature would be higher than 100°F. A thorough heat transfer analysis would be required to determine the appropriate heat trace temperature for this condition.

The maximum heat trace temperature for stagnant flow is 100°F (37.8 C), the lowest temperature calculated using the three criteria.

E. Thermal Conductivity – Heat Gain or Loss

The thermal conductivity of fiberglass piping is approximately 1/100 that of steel, making it a poor conductor of heat compared to steel. However, the use of insulation to prevent heat loss or gain is recommended when there are economic consequences due to heat loss or gain. Typical fiberglass thermal conductivity values vary from 0.07-0.29 BTU/(Ft.)(Hr.)(°F).

F. Thermal Expansion in Buried Pipe

Soil restraint inherently restrains movement of buried fiberglass pipelines because these pipes develop relatively small forces during a temperature change. Special precautions (thrust blocks, guides, expansion joints, etc.) for handling thermal expansion are not necessary if the pipe is buried at least two to three feet and the bedding material is of a soil type capable of restraining the line. Sand, loam, clay, silt, crushed rock and gravel are suitable bedding for restraining a pipeline; however, special precautions must be taken to properly anchor the pipe in swamps, bogs, etc. where bedding might easily shift and yield to even the low forces developed in fiberglass pipe.

G. Pipe Torque Due to Thermal Expansion

Torsion shear stresses in piping systems containing mul- tiple elevation and directional changes normally do not have to be considered in pipe analysis. The allowable bending moments are lower than the allowable torsional moments in a pipe. Therefore, bending moments in a pipe leg reacted by torsion in a connecting pipe will be limited by the bending moment capability of the pipe not the torsional load. Computer modeling is recommended for this sophisticated level of piping system analysis.

12.2 AQAP PIPES SUPPORTS METHODOLOGY

Fiberglass piping engineers use three basic structural components to design a piping system. They are the support, anchor, and guide.

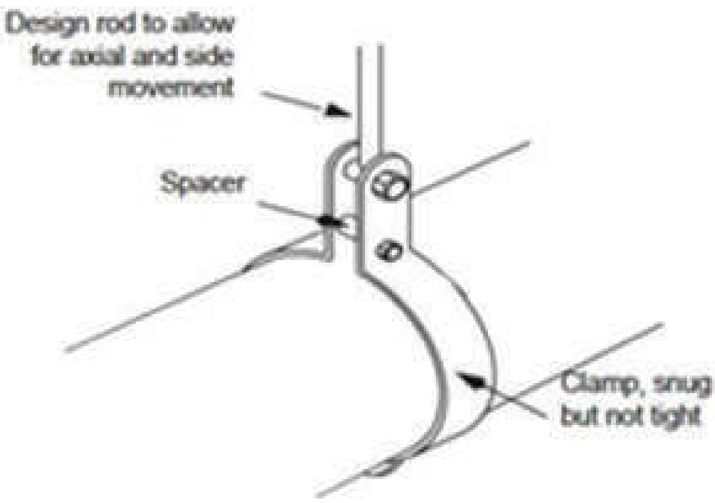
Support
Pipe supports hold the pipe in position and when properly spaced prevent excessive deflections due to the weight of the pipe, fluid, external insulation, and other loads.

Anchor
Pipe anchors restrain axial movement and applied forces. These forces may result from thermal loads, water hammer, vibrating equipment, or externally applied mechanical loads.

Guide
Pipe guides prevent lateral (side-to-side) movement of the pipe. Guides are required to prevent the pipe from buckling under compressive loading. For example: When anchors are used to control thermal expansion, guides are always required.

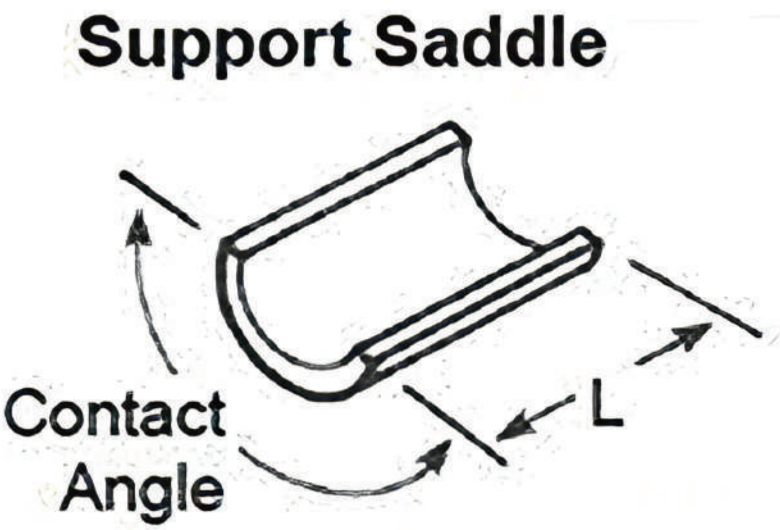
A. Support Bracket Design
The hanger support in Figure 12-4 must have sufficient contact areas to distribute the load. The preferred circumferential load bearing contact is 180°. Refer to Tab 15 for minimum width requirements. When less than 180° of circumference contact and/or larger diameters are encountered, support saddles as shown in Figure 2.1 are recommended.

Figure 12-4



For sizes 16-24-inch, the support bracket bearing stress should not exceed 0.35 Mpa. The use of support saddles with these pipe sizes is recommended. Refer to Figure 12-5

Figure 12-5



For sizes 16-24-inch, the support bracket bearing stress should not exceed 0.35 Mpa. The use of support saddles with these pipe sizes is recommended. Refer to Figure 12-5

1. Use the pipe diameter as the minimum saddle length.

Typical applications using support saddles are shown in Figure 12-6 and 12-7. The support saddles should be bonded to the pipe wall.

Figure 12-6

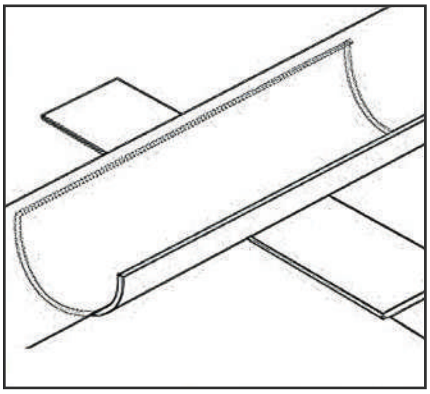
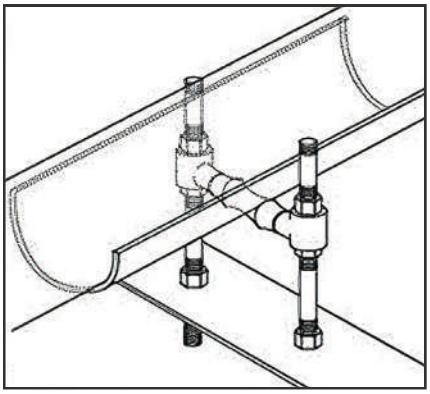


Figure 12-7



The substructure design should include the static weight of the pipe, fluid, and any external loads such as insulation, wind, ice, snow, and seismic.

Guide Design

B. Typical Guide Usage

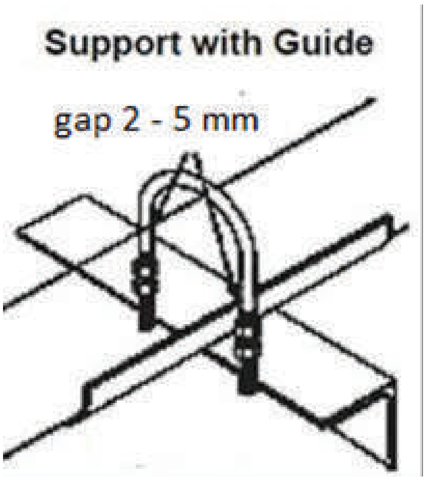
1. Between anchors to prevent buckling of pipeline at elevated temperatures.
2. Near entry points of expansion joints and loops to ensure proper functionality.
3. To provide system stability.

Properly designed and installed guides prevent the pipe from sliding off support beams and allow the pipe to freely move in the axial direction. Guides should be used with 180° support saddles to reduce wear and abrasion of the pipe walls.

Figure 12-8 shows a common method of guiding fiberglass pipe. A clearance of 1/16 to 1/8-inch is recommended between the guide and the support saddle. A 180° support "wear" saddle is recommended to prevent point contact between the U-bolt and pipe. The U-bolt should not be tightened down onto the pipe.

It should be tightened to the structural support member using two nuts and appropriate washers. A 1/8-inch clearance is recommended between the U-bolt and the top of the pipe.

Figure 12-8



Eight-inch diameter and larger pipe are generally allowed more clearance than smaller sizes. The determination of acceptable clearance for these sizes is dependent on the piping system and should be determined by the project piping engineer.

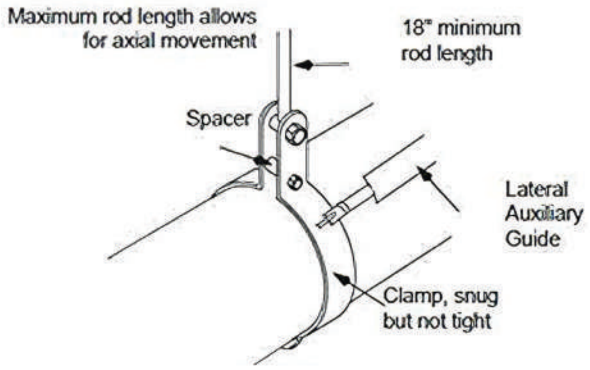
Another design practice is to use U-straps made from flat rolled steel instead of U-bolts. Flat U-straps are less apt than U-bolts to "point" load the pipe wall. U-strap use is most common when guiding pipe sizes greater than 6-inches diameter.

When U-bolts are used in vertical piping, then two 180° wear saddles should be used to protect the pipe around its entire circumference. It is appropriate to gently snug the U-bolt if a 1/8-inch thick rubber pad is positioned between the U-bolt and the saddle. If significant thermal cycles are expected, then the U-bolts should be installed with sufficient clearance to allow the pipe to expand and contract freely. See the "Vertical Riser Clamps" section for additional options in supporting vertical piping.

Figure 12-9 shows a more sophisticated pipe hanger and guide arrangement. It may be used without wear saddles as long as the tie rod allows free axial movement.

Figure 12-9

PIPE HANGER WITH LATERAL GUIDE

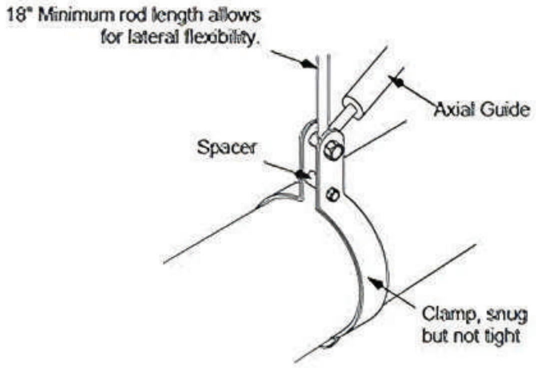


Lateral loading on guides is generally negligible under normal operating conditions in unrestrained piping systems. In restrained piping systems, guides provide the stability required to prevent buckling of pipelines under compressive loads. If the guides are located properly in the pipeline, the loads required to prevent straight pipe runs from buckling will be very small.

Upset conditions can result in significant lateral loads on the guides and should be considered during the design phase by a qualified piping engineer. Water hammer and thermal expansion or contraction may cause lateral loading on guides near changes in direction. Therefore, it is always prudent to protect the pipe from point contact with guides near changes in directions and side runs.

Figure 12-10 shows a pipe hanger with an axial guide using a double bolt pipe clamp arrangement. This support provides limited axial stability to unrestrained piping systems.

Figure 12-10



Pipelines supported by long swinging hangers may experience instability during rapid changes in fluid flow.

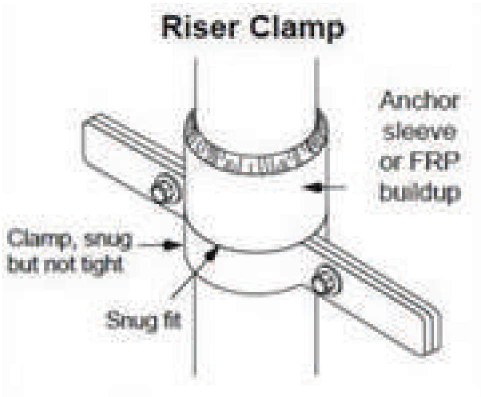
Vertical Riser Clamps

Riser clamps as shown in Figure 12-11 may act as simple supports, as well as guides, depending upon how they are attached to the substructure. The clamp should be snug but not so tight as to damage the pipe wall. The use of an anchor sleeve bonded onto the pipe is required to transfer the load from the pipe to the riser clamp. See the "Anchor Designs" section for detailed information concerning the anchor sleeve or FRP buildup.

It is important to note that this type of clamp only provides upward vertical support. Certain design layouts and operating conditions could lift the pipe off the riser clamp. This would result in a completely different load distribution on the piping system. A pipe designer needs to consider whether the column will be under tension, or in a state of compression. Additional guides may be required to prevent unwanted movement or deflection.

A qualified piping engineer should be consulted to ensure an adequate design.
Riser clamps designed to provide lateral support should incorporate support saddles to distribute the lateral loads.

Figure 12-11



C. Anchor Design

Anchor Usage

1. To protect piping at "changes-in-directions" from excessive bending stresses.
2. To protect major branch connections from primary pipeline induced shears and bending moments.
Particular consideration should be given to saddle and lateral fitting side runs.
3. Installed where fiberglass piping is connected to steel piping and interface conditions are unavailable.
4. To protect a piping system from undesirable movement caused by water hammer or seismic events.
5. To protect sensitive in-line equipment.
6. To absorb axial thrust at in-line reducer fittings when fluid velocities exceed 3 m/sec.
7. To provide stability in long straight runs of piping.

To be effective, an anchor must be attached to a sub structure capable of supporting the applied forces. In practice, pumps, tanks, and other rigidly fixed equipment function as anchors for fiberglass piping systems.

Anchors as previously described are used to provide axial restraint to piping systems. In most cases an anchor provides bidirectional lateral support to the pipe thus acting like both a support and guide. Furthermore, anchors can be designed to provide partial or complete rotational restraint. But this is not normally the case in practice. Figures 12-12 through 12-15 show typical methods of anchoring fiberglass piping systems.

Figure 12-12

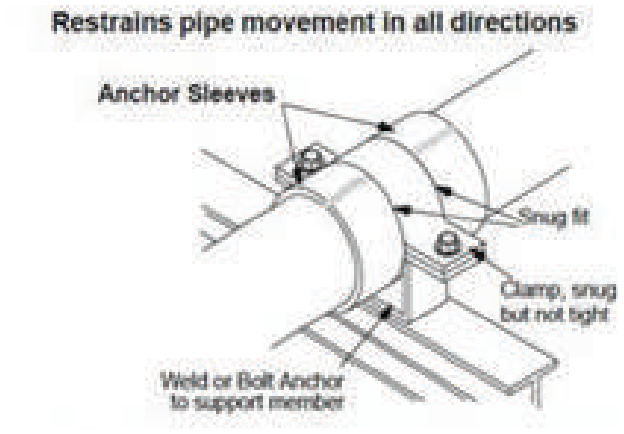


Figure 12-13

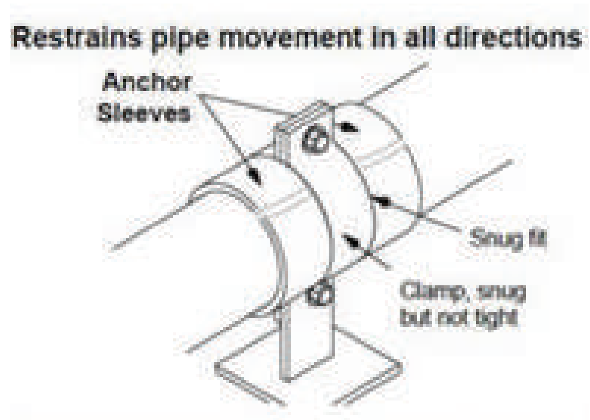


Figure 12-14

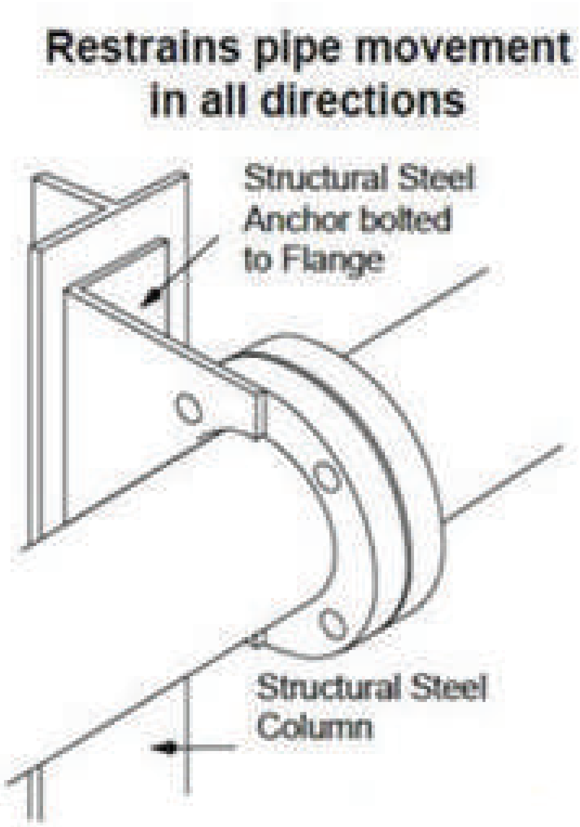


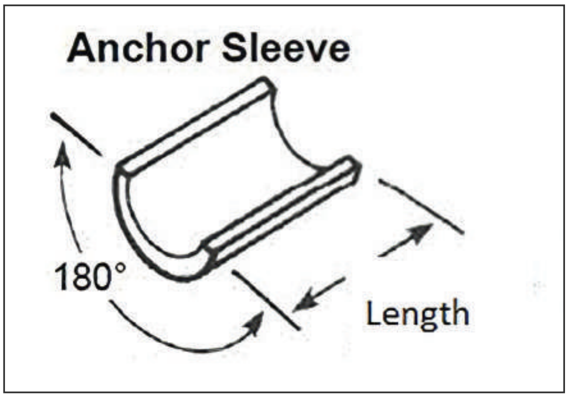
Figure 12-15

The reactions generated at anchors when restraining large thermal loads can be significant and should be calculated by a qualified piping engineer. The anchor brackets and substructure design should be designed with sufficient stiffness and strength to withstand these loads combined with any other system loads. Other system loads may include water hammer, seismic, static weight of pipe, fluid, and any external loads such as insulation, wind, ice, and snow.

Anchor Sleeves

An anchor sleeve as shown in Figure 12-6 is necessary to transfer axial load from a pipe body to an anchor bracket. Pairs of anchor sleeves are bond- ed to the outer surface of a pipe to provide a shear load path around the complete circumference of the pipe body. To restrain pipe motion in two directions, two pairs of anchor sleeves are required. They must be bonded on both sides of an anchor bracket to completely restrain a pipe axially. There are design conditions where only one set of anchor sleeves is required. The piping engineer should make this determination.

Figure 12-6



D. Piping Support Span Design

A support span is the distance between two pipe supports. Proper support span lengths ensure the pipe deflections and bending stresses are within safe working limits. For static weight loads, it is standard practice to limit the maximum span deflection in horizontal pipe lines to Ω" and the bending stresses to ⅛ of the ultimate allowable bending stress. Fiber Glass Systems applies these design limits to the engineering analysis used to determine the allowable support spans.

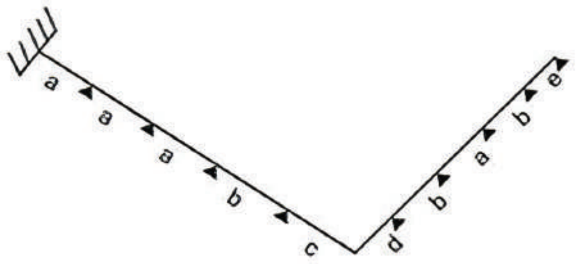
Span Analysis Methodology

The maximum allowable piping support spans are determined using the "Three Moment Equations" for uniformly loaded continuous beams. The equations may be modified to represent various end conditions, load types, and even support settlements. Refer to Appendix A for the fundamental equations. Fiber Glass Systems uses these equations to calculate the bending moments in piping spans. The pipe bending stresses and deflections are then evaluated for compliance with the aforementioned design criteria.

Figure 12-17

Piping Span Adjustment Factors With Unsupported Fitting at Change in Direction

	Span Type	Factor
a	Continuous interior or fixed end spans	1.00
b	Second span from simple supported end or unsupported fitting	0.80
c + d	Sum of unsupported spans at fitting	≤ 0.75*
e	Simple supported end span	0.67



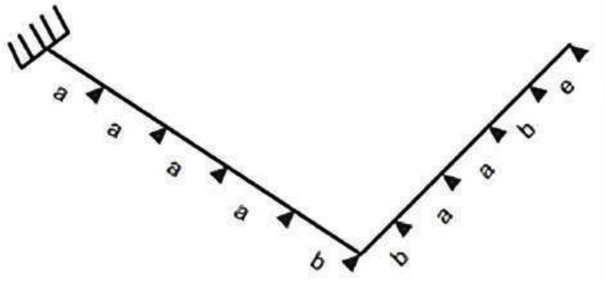
*For example: If continuous support span is 10 ft., c + d must not exceed 7.5 ft. (c = 3 ft. and d = 4.5 ft. would satisfy this condition).

To avoid lengthy engineering calculations, our individual product bulletins contain recommended piping support span lengths. These span lengths are easily modified to match fluid specific gravity, operating temperatures, and end conditions. Figures 12-and 2.14 provide span adjustment factors for various end conditions found in most horizontal piping system layouts. Tables for fluid specific gravity and temperature adjustment factors are product unique. Please refer to the product data bulletins for detailed design information.

Figure 12-18

Piping Span Adjustment Factors With
Supported Fitting at Change in Direction

	Span Type	Factor
a	Continuous interior or fixed end spans	1.00
b	Span at supported fitting or span adjacent to a simple supported end	0.80
e	Simple supported end span	0.67



Support Design Summary

1. Do not exceed the recommended support span.
2. Support valves and heavy in-line equipment independently. This applies to both vertical and horizontal piping.
3. Protect pipe from external abrasion at supports.
4. Avoid point contact loads.
5. Avoid excessive bending. This applies to handling, transporting, initial layout, and final installed position.
6. Avoid excessive vertical loading to minimize bending stresses on pipe and fittings.
7. Provide adequate axial and lateral restraint to ensure line stability during rapid changes in flow.

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