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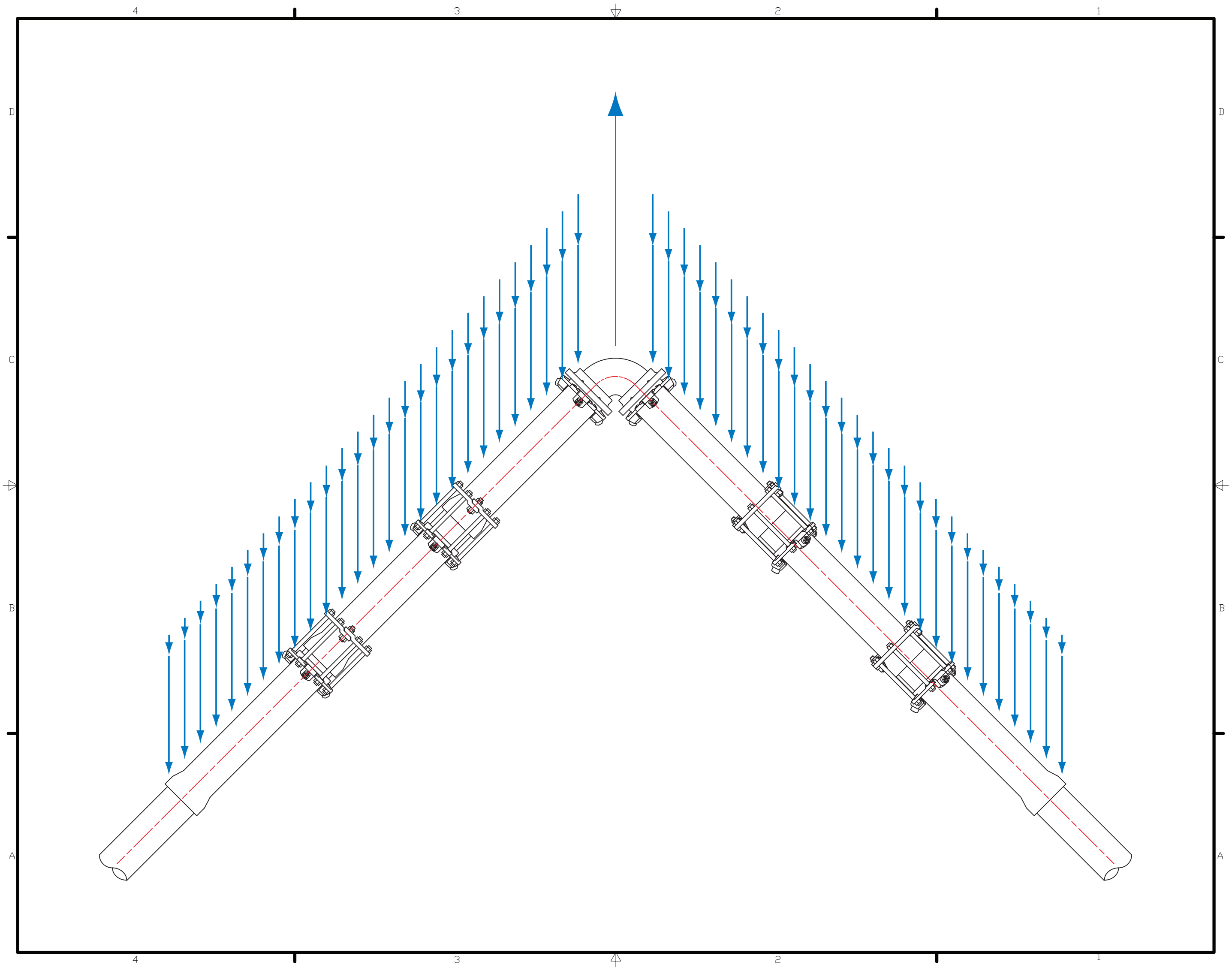
PD - 6

THRUST RESTRAINT DESIGN EQUATIONS AND SOIL PARAMETERS FOR DUCTILE IRON AND PVC PIPE



Thrust Restraint Design Equations and Soil Parameters

These equations and soil parameters are an effort to provide the piping system designer with conservative techniques and parameters for the design of underground restrained joint piping systems. They utilize recognized design equations and conservative soil parameters.

The design equations in this handbook have proven useful in a wide variety of applications since 1982. The soil parameters presented include the results of an extensive study of the actual frictional performance of soils on ductile iron, ductile iron encased with polyethylene, and PVC pipe.

The theory and application of this design method are outlined in a series of “Connections” ™ bulletins [PD-01 through PD-05]. These bulletins can be obtained from EBAA Iron Sales [www.ebaa.com]. A computer program utilizing all the information provided in these bulletins and this booklet is also available from EBAA Iron Sales.

These equations and soil values have proven conservative over the years and are dependent upon accurate soil identification and classification and good installation procedures and inspection. The ultimate responsibility for the identification of soil type, the proper use of the data provided, the final design, and the inspection of the system must rest with the design engineer.

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Definition of Terms

A = Cross sectional area of the pipe, in^2

A_b = Cross sectional area of the branch of a tee, in^2

A_l = Cross sectional area of the large side of a reducer, in^2

A_p = Area based on half of the pipe circumference in contact with the soil, $\frac{ft^2}{ft}$

$(A_p)_b$ = Area based on full pipe circumference in contact with the soil, $\frac{ft^2}{ft}$

A_s = Cross sectional area of the small side of reducer, in^2

c = Cohesion of the soil, $\frac{lbs}{ft^2}$

D = Outside diameter of the pipe, ft

f_c = Cohesion modifier coefficient

F_s = Frictional resistance acting on the pipeline (acting on half of the pipe diameter), $\frac{lbs}{ft}$

F_{sb} = Frictional resistance acting on the pipeline (acting on the full pipe diameter), $\frac{lbs}{ft}$

$(F_{sb})_l$ = F_{sb} on the large side of a reducer, $\frac{lbs}{ft}$

f_Φ = Friction angle modifier coefficient

H_c = Mean depth from surface to pipe center line, ft

K_n = Trench compaction modifier

K_p = Rankin passive pressure coefficient

L = Minimum restrained length for bends, ft

L_b = Minimum restrained length for the branch of a tee, ft

L_l = Minimum restrained length for the large side of a reducer, ft

L_r = Minimum restrained length on each side of the run of a tee, ft

P = Internal pressure, $\frac{lbs}{in^2}$

R_s = Bearing resistance acting on the pipeline, $\frac{lbs}{ft}$

S_f = Safety Factor

s_u = Undrained shear strength, $\frac{lbs}{ft^2}$

T = Resultant thrust force, lbs

W = Normal force acting on the pipeline, $\frac{lbs}{ft}$

W_e = Normal force due to the vertical prism load of the soil, $\frac{lbs}{ft}$

W_p = Normal force due to the weight of the pipe, $\frac{lbs}{ft}$

W_w = Normal force due the weight of the water in the pipe, $\frac{lbs}{ft}$

Φ = Internal friction angle of the soil, degrees

γ = Soil density, $\frac{lbs}{ft^3}$

Θ = Bend angle, degrees

σ_h = Horizontal passive soil pressure, $\frac{lbs}{ft^2}$

Bearing Resistance

Rankin Passive Pressure theory for soils states

$$\sigma_h = \gamma H_c K_p + 2c\,\sqrt{K_p}$$

where

$$K_p = \tan^2 (45 + \Phi / 2)$$

Therefore, the bearing resistance along the pipeline is denoted by the term "R_s" and is represented as

$$R_s = K_n\,\sigma_h D$$

Frictional Resistance

The frictional resistance acting on a pipeline, "F_s", can be determined by an adaptation of Potyondy's equation.

$$F_s = A_p(f_c c) + W \tan(f_\Phi \Phi)$$

where

$$A_p = \pi D / 2$$

$$W = 2W_e + W_p + W_w$$

When analyzing the branch of a tee, reducers, or dead ends, the full pipe circumference should be taken into account since the full surface of the pipe is moving longitudinally into the soil. This modified version of the frictional force is denoted as

$$F_{sb} = (A_p)_b(f_c c) + W \tan(f_\Phi \Phi)$$

where

$$(A_p)_b = \pi D$$

The frictional values for the soil should always be based on the soil that is in contact with the pipe. The pipe friction tests also indicated that ductile iron pipe encased with polyethylene (PE) film slips inside of the polyethylene encasement. This lends itself to conventional friction theory where the coefficient of friction of polyethylene on a ductile iron pipe surface was determined to be the tangent of 14 degrees. Therefore, for PE encased ductile iron pipe $F_s = F_{sb} = W \tan 14 = 0.249W$

Table lists the properties for most soils. Figure 1 lists the soils classifications from ASTM D2487

Soil Group	f_c		c	f_Φ		Φ	γ	K_n Trench Type		
	DIP	PVC	(psf)	DIP	PVC	(deg)	(pcf)	3	4	5
GW, SW	0	0	0	1.0	0.7	36	110	0.60	0.85	1.00
GP, SP	0	0	0	1.0	0.7	31	110	0.60	0.85	1.00
GM, SM	0	0	0	1.0	0.7	30	110	0.60	0.85	1.00
GC, SC	0.4	0.2	225	1.0	0.6	25	100	0.60	0.85	1.00
CL	0.5	0.3	250	1.0	0.5	20	100	0.60	0.85	1.00
ML	0	0	0	1.0	0.6	29	100	0.60	0.85	1.00

Table 1. Properties of Soils used for Bedding to Calculate F_s and F_{sb}

Major Divisions			Group Symbols	Typical Names	Classification Criteria		
COARSE-GRAINED SOILS More than 50% retained in No. 200 sieve*	GRAVELS 50% or more of coarse fraction retained on No. 4 sieve	CLEAN GRAVELS	GW	Well-graded gravels and gravel-sand mixtures, little or no fines	Classification on basis of percentage of fines Less than 5% Pass No. 200 sieve GW, GP, SW, SP More than 12% Pass No. 200 sieve GM, GC, SM SC 5% to 12% Pass No. 200 sieve Borderline Classification requiring use of dual symbols	$C_u = D_{60} / D_{10}$ Greater than 4 $C_z = (D_{30})^2 / D_{10} \text{ x } D_{60}$ Between 1 and 3	
			GP	Poorly graded gravels and gravel-sand mixtures, little or no fines		Not meeting both criteria for GW	
		GRAVELS WITH FINES	GM	Silty gravels, gravel-sand-silt mixtures		**Atterberg limits plot below "A" line or plasticity index less than 4.**	**Atterberg limits plotting in hatched area are borderline classifications requiring use of dual symbols.**
			GC	Clayey gravels, gravel-sand-clay mixtures		**Atterberg limits plot above "A" line and plasticity index greater than 7.**	
	SANDS More than 50% of coarse fraction passes No. 4 sieve	CLEAN SANDS	SW	Well-graded sands and gravelly sands, little or no fines		$C_u = D_{60} / D_{10}$ Greater than 6 $C_z = (D_{30})^2 / D_{10} \text{ x } D_{60}$ Between 1 and 3	
			SP	Poorly graded sands and gravely sands, little or no fines		Not meeting both criteria for SW	
		SANDS WITH FINES	SM	Silty sands, sand-silt mixtures		**Atterberg limits plot below "A" line or plasticity index less than 4.**	**Atterberg limits plotting in hatched area are borderline classifications requiring use of dual symbols.**
			SC	Clayey sands, sand-clay mixtures		**Atterberg limits plot above "A" line and plasticity index greater than 7.**	
FINE-GRAINED SOILS 50% or more passes No. 200 sieve*	SILTS AND CLAYS Liquid limit 50% or less		ML	Inorganic silts, very fine sands, rock flour, silty or clayey fine sands			
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays			
			OL	Organic silts and organic silty clays of low plasticity			
	SILTS and CLAYS Liquid limit greater than 50%		MH	Inorganic silts, micaceous or diatomaceous fine sands or silts, elastic silts			
			CH	Inorganic clays of high plasticity, fat clays			
			OH	Organic clays of medium to high plasticity			
Highly Organic Soils			PT	Peat, muck and other highly organic soils			

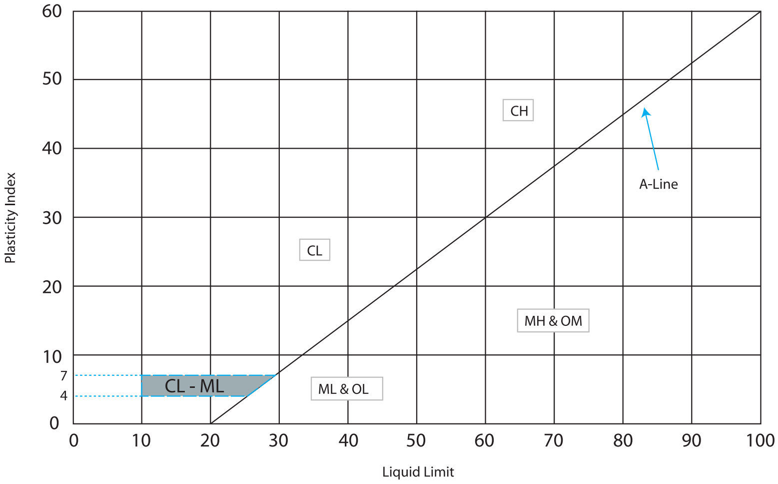
PLASTICITY CHART

For classification of fine-grained soils and fine fraction or coarse-grained soils.

Atterberg limits plotting in hatched area are borderline classifications requiring use of dual symbols.

Equation of A-line:

$$PI = 0.73 (LL -20)$$



*Based on a material passing the 3-in. (75-mm) sieve.

Figure 1. The Unified Soil Classification System - ASTM D2487 (Reprinted With Permission)

Special Soil Conditions

The values in Tables 2 and 3 are for near saturated, undisturbed soils, type CL, ML, CH, and MH with pipe surrounded with sand or gravel having a minimum Standard Proctor Density of 80% or greater. While these values are conservative for most situations, a competent soils engineer should be contacted for pipelines in wetlands, river bottoms, etc.

Soil Group	$c = S_u$ (psf)	γ (pcf)	K_n		
			3	4	5
CL	450	100	0.60	0.85	1.00
CH	400	100	0.40	0.60	0.85
ML	300	100	0.60	0.85	1.00
MH	250	100	0.40	0.60	0.85

(Note: The above values are for undisturbed soil)

Table 2. In Situ Values of Soil Properties for R_s

Soil Group	f_c		c	f_Φ		Φ
	DIP	PVC		DIP	PVC	
GP & SP	0	0	0	1.00	0.70	31

Table 3. Bedding Soil Properties for F_s

Bends

The resultant thrust force for bends is

$$T = 2PA \sin(\Theta / 2)$$

Horizontal Bend

$$L = S_f PA \tan(\Theta / 2) / (F_s + 1/2\, R_s)$$

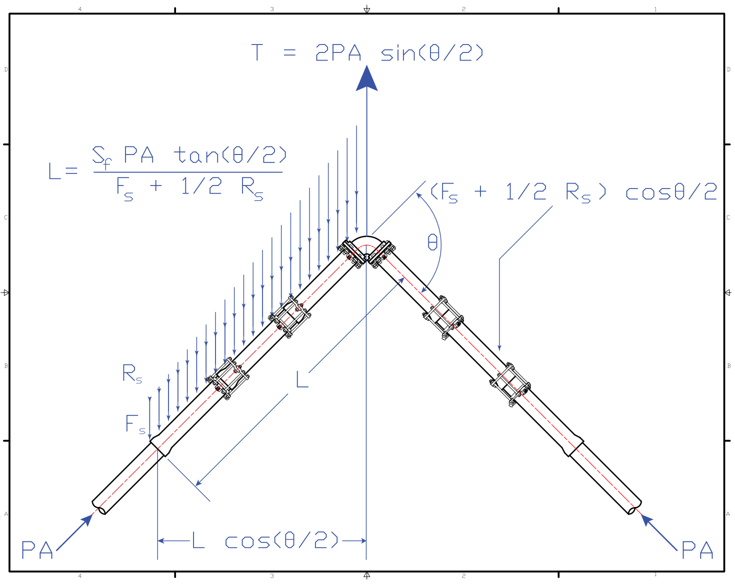


Figure 2. Horizontal Bend

Vertical Down Bend

$$L = S_f PA \tan(\Theta / 2) / F_s$$

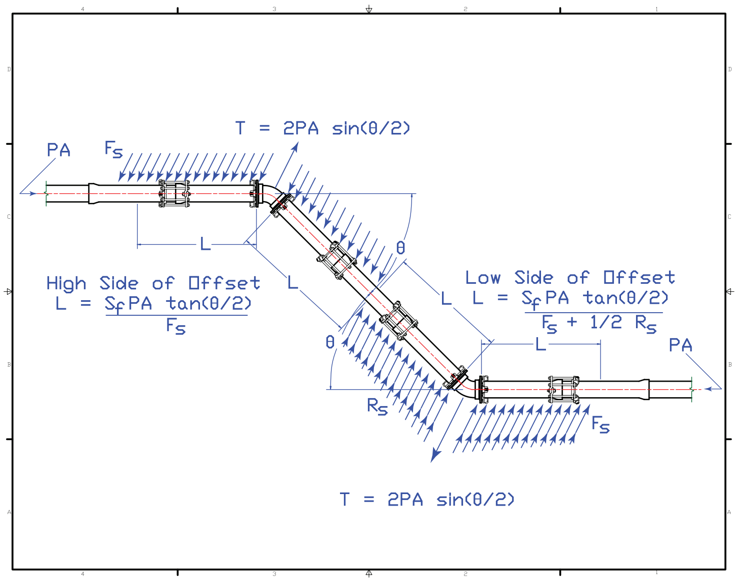


Figure 3. Vertical Down Bend Shown On Vertical Offset

For vertical offsets use the equation for the vertical down bend for the upper bend and the equation for the horizontal bend for the lower bend.

Tees

$$L_b = S_f(PA_b - R_s L_r) / F_{sb}$$

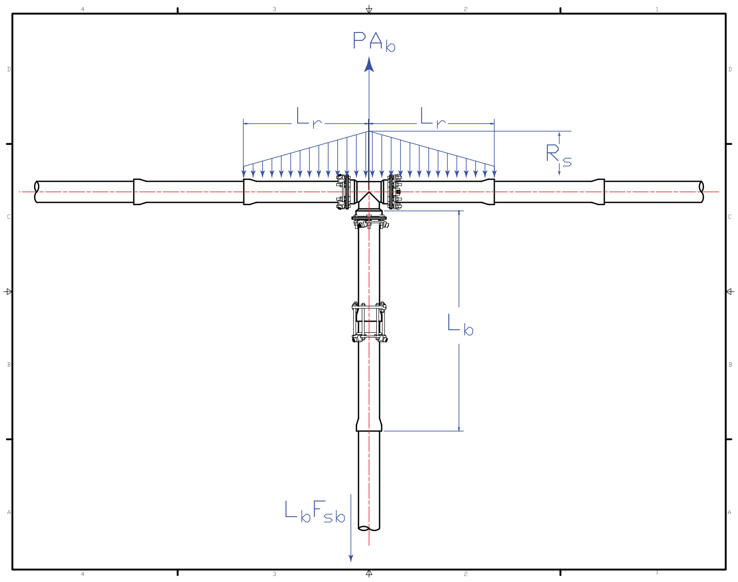


Figure 4. Tee

Reducers

Restrained length on the large side.

$$L_l = S_f P(A_l - A_s) / (F_{sb})_l$$

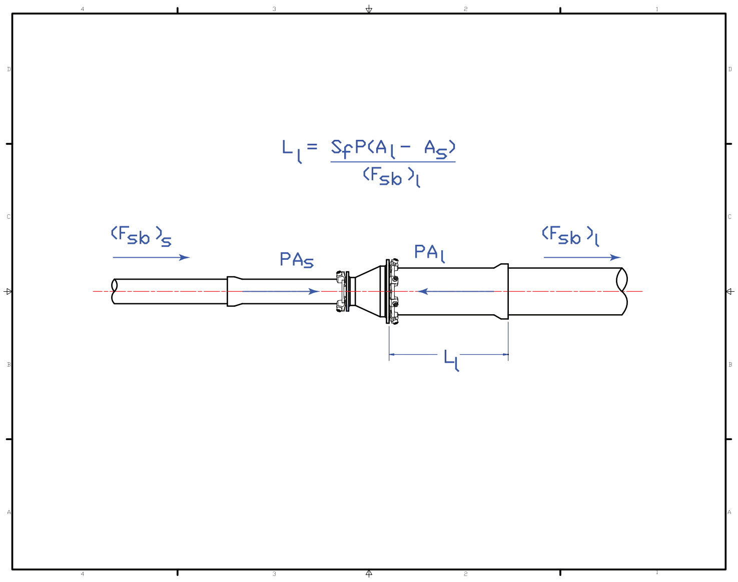


Figure 5. Reducer

Dead Ends

$$L = S_f PA / F_{sb}$$

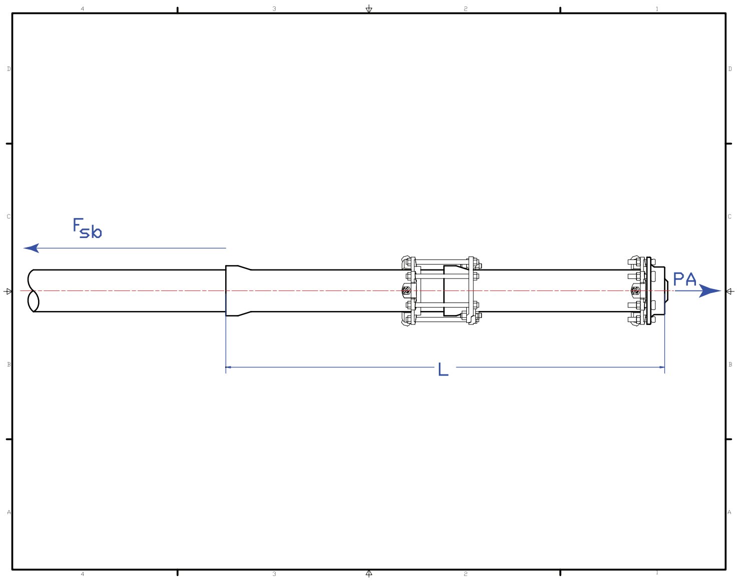


Figure 6. Dead Ends

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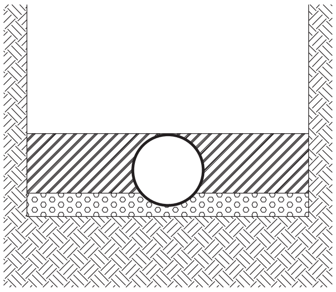
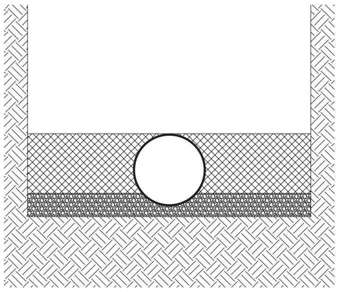


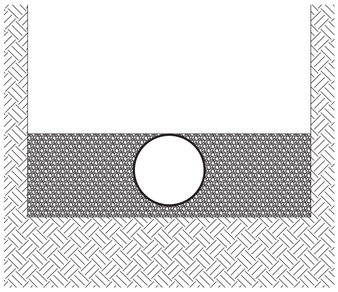
Type 3

Pipe bedded in 4 inches minimum loose soil.
Backfill lightly consolidated to top of the pipe.



Type 4

Pipe bedded in sand, gravel, or crushed stone to depth of ⅛ pipe diameter, 4 inch minimum.
Backfill compacted to top of pipe. (Approximately 80 percent standard Proctor, AASHTO T-99)



Type 5

Pipe bedded in compacted granular material to the center line of pipe, 4 inches minimum under pipe. Compacted granular or select material to top of pipe. (Approximately 90 percent standard Proctor, AASHTO T-99)

“Loose Soil” or “Select Material” is defined as native soil excavated from the trench, free of rocks, foreign material, and frozen earth.

Figure 7. ANSI/AWWA C150/A21.50 Trench Conditions

Table 4. Nominal Dimensions and Weights

Nominal Pipe Size	Outside Diameter (feet)		Cross Sectional Area (sq. in.)	$W_p + W_w$	
	DI	PVC		DI	PVC
3	0.33		12.32	14.0	
4	0.40	0.40	18.10	19.0	8.3
6	0.58	0.58	37.39	32.0	17.1
8	0.75	0.75	64.33	50.0	29.5
10	0.93	0.93	96.77	71.0	44.3
12	1.10	1.10	136.85	96.0	62.7
14	1.28	1.28	183.85	126.0	84.2
16	1.45	1.45	237.79	158.0	108.9
18	1.63	1.63	298.65	192.0	136.8
20	1.80	1.80	366.44	230.0	167.9
24	2.15	2.15	522.79	317.0	239.5
30	2.67	2.67	804.25	466.0	368.5
36	3.19	3.19	1152.09	653.0	527.8
42	3.71		1555.28	868.0	
48	4.23		2026.83	1118.0	
54	4.76		2560.72	1407.0	

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