PLASTIC PIPE DESIGN MANUAL

Vylon Pipe

Plastic Pipe Design Manual

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A. Introduction

This Design Guide is provided to aid owners, engineers and contractors in the design of flexible pipe. The Guide provides a basic understanding of the interaction of the soil/pipe structure. This Guide does not serve as an in depth text to theoretical formula derivation, but as a more practical Guide for today's design engineer and contractor.

The emphasis of the Guide is on flexible PVC pipe, but the design issues addressed do apply to all flexible pipe. Since different types of material, (PVC, ductile iron pipe, polyethylene, fiberglass, corrugated metal), have different material properties, a critical design issue for a particular type of material may not be covered in this Guide. For example, some materials may require a check of pipe wall strain due to environmental strain corrosion concerns or checking small deflection limits to insure a pipe’s lining does not spall off.

The information provided in this Design Guide represents the many years of proven understanding of the performance and design of flexible pipe. The continued evolution of the design of flexible pipes have built upon the early theories which still provide reliable conservative results. Most of the more recent work in flexible pipe design theory is in the area of finite element design. This more rigorous design approach is best suited to address special design considerations, not the typical sewer design.

The Design Guide is formatted to take the designer through the design procedure. Following this introduction, the Guide starts with a review of the design approach for both direct bury and sliplining applications. The next section includes detailed formulae and data necessary to perform the design. The final section provides all of the information required to perform a design for the various Vylon Pipe products. Footnotes and a bibliography are included for referenced sources.

B. Design Approach

1. Direct Bury

Flexible pipes have been used for standard direct bury applications since the early days of corrugated metal pipe in the 1870's. The early uses of flexible pipe were mainly for storm drainage and culverts. As the acceptance grew, flexible pipes started being used for sewer application.

The early designs of flexible pipe were based on extensions of rigid pipe theory. Work by Dr. M.G. Spangler and Reynold K. Watkins in the 1920's lead to the design theories still in use today. Their fundamental understanding of the soil/pipe interaction design approach has led to billions of feet of flexible pipe being successfully installed.

For direct bury application, deflection control is generally considered the governing design criteria. Although flexible pipes can be deflected 30% without reverse curvature, generally either 5 or 7.5% deflection is used in design. This low level of deflection has been chosen to address service issues, not structural concerns. Some of these service issues include ease of cleaning as well as tapping in new service laterals.

The design approach typically used is:

a. Calculate the load on the pipe, both dead and live loads.

b. Calculate deflection. If the deflection is too great either increase pipe stiffness or change pipe embedment material. Changing embedment material will have a much greater impact on controlling deflection than increasing pipe stiffness.

c. Check buckling resistance for confined, unconfined and hydrostatic conditions.

d. Check wall crush.

2. Sliplining

Sliplining is one of the oldest methods of pipeline rehabilitation with millions of feet of pipe installed. Sliplining has been proven to be a cost effective method of pipeline rehabilitation with a minimal amount of disruption.

Although the design equations used for a slipliner pipe are the same as those used for direct bury installation, generally the controlling design factor is buckling. This is especially true in many of the newer rehabilitation products which have a low stiffness. Products with a strength, or pipe stiffness, similar to a direct bury pipe usually do not have problems with buckling.

When checking the buckling resistance of a Slipliner pipe, conditions during grouting and after grouting must be considered. During the grouting operation, the pipe is not confined and its unconfined buckling resistance versus the grouting pressure must be checked. Once the pipe is grouted, the long term buckling resistance should be checked.

Like all flexible pipes, deflection calculations should be performed for pipe installed by sliplining. A very conservative approach is to not consider the existing pipe in the calculations. Since the slipliner will probably be grouted, the design is treated as a flexible pipe in a stiff backfill with a conservative E' of 1500 - 2000 psi.

The design approach typically used is:

a. Determine the following:

- Pipe Stiffness
- Grouting Pressure
- Water Table Level

b. Calculate the load on the pipe, both Live Load and Dead Load.

c. Calculate Deflection.

d. Check buckling resistance for confined, unconfined and hydrostatic buckling.

e. Check wall crush.

The remainder of this Design Guide includes all the necessary equations, and tables to perform the above design requirements. In Section E, specific physical properties and other information for Vylon Pipe Insider Pipe and Vylon Slipliner Pipe is included.

C. Design Criteria

1. Pipe Loading, P_y

The loading on a buried pipe is comprised of two elements, dead load and live load. The dead load is the pressure exerted on the pipe by the weight of the soil or some stationary mass above the pipe. The live load is the pressure exerted by a moving object passing over top of the pipe. The method for determining the pipe load is the addition of the dead and live load. The formula for pipe load is:

$$P_y = DL + LL$$

P_y = Pipe Load, lb/in^2
DL = Dead Load, lb/in^2
LL = Live Load, lb/in^2

a. Dead Load, *DL*

In 1913, Professor Anson Marston developed the Marston Theory of Loads. This theory is used to determine the load imposed by the soil column above a pipe. The theory encompasses many different types of loading situations, trench conditions, embankment, etc.

The main formula used in determining the earth load on a flexible pipe is the prism load developed by Marston. The prism load determines the weight of the soil column directly above the pipe. The prism load condition neglects any factors, such as side wall friction, which could reduce the loading on the pipe. The prism load tends to be a conservative approach and calculates the long term load imposed on the pipe. **When the prism load is used to calculate deflection, the calculated value is the long term deflection.**

The formula used to calculate the prism load is:

$$DL = \frac{\gamma \cdot H}{144}$$

DL = Dead Load, lb/in^2
γ = Soil Unit Weight, lb/ft^3
H = Height of Cover, ft

b. Live Load, *LL*

The live load is the second type of loading which can be imposed on a buried pipe. The live load is imposed by a source moving over the buried pipe such as vehicles on a road, railroad, or at an airport. The determination of live load is important for pipe with shallow burial of less than 8 feet. The effects of live loads decrease as the depth of cover increases. There are many methods to calculate the live loads. A table of live loads has been developed for the three standard load conditions, highway, railroad, and airport. The values in Table 1 are from Uni-Bell's "Handbook of PVC Pipe"[1].

[1]Unibell, *Handbook of PVC Pipe,* Uni-Bell PVC Pipe Association, Dallas, Texas, 1991, pg. 194.

TABLE 1

Live Loads on Flexible Pipe

Height of Cover (ft)	Live Load Highway[1] H20 (lb./in²)	Railway[2] E80 (lb./in²)	Airport[3] (lb./in²)
1	12.50	N.R.	N.R.
2	5.56	26.39	13.14
3	4.17	23.61	12.28
4	2.78	18.40	11.27
5	1.74	16.67	10.09
6	1.39	15.63	8.79
7	1.22	12.15	7.85
8	0.69	11.11	6.93
10	N.S.	7.64	6.09
12	N.S.	5.56	4.76
14	N.S.	4.17	3.06
16	N.S.	3.47	2.29
18	N.S.	2.78	1.91
20	N.S.	2.08	1.53
22	N.S.	1.91	1.14
24	N.S.	1.74	1.05
26	N.S.	1.39	N.S.
28	N.S.	1.04	N.S.
30	N.S.	0.69	N.S.
35	N.S.	N.S.	N.S.
40	N.S.	N.S.	N.S.

Notes:

1. Simulates 20 ton truck traffic + impact
2. Simulates 80,000 lb/ft railway load + impact
3. 180,000 lbs. dual tandem gear assembly. 26 inch spacing between tires and 66 inch center-to-center spacing between fore and aft tires under a rigid pavement 12 inches

N.S. = Not Significant

N.R. = Not Recommended

1 lb/in^2=144 lb/ft^2

2. Deflection Calculation, Δ

A flexible pipe is defined as a conduit which will deflect at least two percent without any sign of structural distress, such as wall cracking. The ability to deflect is the key to the strength of the pipe-soil structure. The deflection of the pipe allows soil consolidation and results in soil arching which relieves the flexible pipe of the majority of the vertical soil load.

While deflection is an important part of developing strength in a flexible pipe installation, deflection must be controlled to insure proper pipe performance. Various pipe materials can withstand different levels of deflection without structural damage. A deflection limit of 5 or 7.5% has become the standard for limiting deflection in flexible pipes. The above deflection limit has been chosen to address service issues, not structural concerns.

The Modified Iowa Formula is the most commonly used method to predict the deflection of a flexible pipe. The formula was developed in 1958 by Dr. Reynold K. Watkins as a modification of the Iowa Formula work of Dr. Merlin Spangler in 1927. The Modified Iowa Formula is:

$$\Delta = \frac{D_L \cdot K \cdot P_y}{(.149 \cdot PS) + (0.061 \cdot E')} \cdot 100$$

Δ = *Deflection, %*
D_L = *Deflection Lag Factor*
K = *Bedding Constant*
P_y = *Prism Load, lb/in*^{2}
PS = *Pipe Stiffness, lb/in*^{2}
E' = *Soil Modulus, lb/in*^{2}

The steps to determining the deflection of a flexible pipe are:

- Determine or calculate the pipe stiffness, *PS*,
- Set the deflection lag factor, D_L, to 1.0,
- Calculate the pipe load, P_y,
- Choose the appropriate soil modulus, E',
- Choose the bedding constant or use $K = .1$,
- Calculate the deflection, Δ.

a. Pipe Stiffness, *PS*

Pipe stiffness is the inherent strength of a flexible pipe. Pipe stiffness is determined by testing in accordance to ASTM D 2412 "Standard Test Method for External Loading Properties of Plastic Pipe by Parallel Plate Method". In the Parallel Plate Method, the pipe is deflected 5% and the load is recorded. The resulting pipe stiffness is:

$$PS = F / \Delta Y / L$$

PS = *Pipe Stiffness, lb/in*^{2}
F = *Force, lb*
ΔY = *Vertical Deflection, in*
L = *Sample Length, in*

The pipe stiffness can also be determine theoretically by the following equation:

$$PS = \frac{6.71EI}{r^3}$$

PS = *Pipe Stiffness, lb/in²*
E = *Modulus of Elasticity, lb/in²*
I = *Moment of Inertia, in³*
r = *Mean Pipe radius, in*

Pipe stiffness values should be provided by the pipe manufacturer, or referenced from the appropriate ASTM. The pipe stiffness for all Vylon Pipe products is a minimum of 46 psi.

b. Deflection Lag Factor, D_L

The deflection lag factor is a term which was developed by Spangler for use in the Iowa Formula. The deflection lag factor accounts for long term soil consolidation at the sides of a flexible pipe and the resulting reduction of soil support. **The deflection lag factor is applicable when using any of the Marston loads except the Prism Load.** If the soil loading on the pipe is calculated using any Marston load except for the prism load, Spangler recommended that a deflection lag factor of 1.5 be applied.

When using the prism load to calculate deflection, the deflection lag factor is one because the prism load calculates the ultimate long term load imposed on the pipe.

c. Soil Modulus, *E'*

The soil modulus is a term derived from the original Iowa Formula developed by Spangler. The *E'* was developed to replace the *er* term in the Iowa Formula because the value of *e*, modulus of passive resistance, was not dimensionally correct for a modulus. Many attempts have been made to measure *E'* through calculation, laboratory, and field methods. The most commonly recognized values are those of Amster Howard of the U.S. Bureau of Reclamation. Howard examined information from known laboratory and field tests and developed a table of average *E'* values. These values correlated theoretical computations with actual deflections seen in the field using the Modified Iowa Formula.

The list of values developed by Amster Howard are given as Table 2. The selection of *E'* must not be arbitrarily chosen from the table but should be selected using sound engineering judgment and experience.

TABLE 2

AVERAGE VALUES OF MODULUS OF SOIL REACTION, E'

(For Initial Flexible Pipe Deflection)

Soil type-pipe bedding material (Unified Classification System)	E' for Degree of Compaction of Bedding, in pounds per square inch			
	Dumped	Slight <85% Proctor, <40% relative density	Moderate 85%-95% Proctor, 40%-70% relative density	High, >95% Proctor, >70% relative density
(1)	(2)	(3)	(4)	(5)
Fine-grained Soils (LL>50[b]) Soils with medium to high plasticity CH, MH, CH-MH	No data available; consult a competent soils engineer; Otherwise use E'=0			
Fine-grained Soils (LL<50) Soils with medium to no plasticity, CL, ML, ML-CL,with less than 25% coarse-grained particles	50	200	400	1000
Fine-grained Soils (LL<50) Soils with medium to no plasticity, CL, ML, ML-CL,with more than 25% coarse-grained particles Coarse-grained Soils with Fines GM, GC, SM, SC[c] contains more than 12% fines	100	400	1000	2000
Coarse-grained Soils with Little or no Fines GW, GP, SW, SP[c] contains less than 12% fines	200	1000	2000	3000
Crushed Rock	1000	3000	3000	3000
Accuracy in Terms of Percentage Deflection	± 2	± 2	± 1	± 0.5

[a] ASTM Designation D 2487, USBR Designation E-3.

[b] LL=Liquid Limit.

[c] Or any borderline soil beginning with one of the symbols (i.e. GM-GC,GC-SC).

[d] For 1% accuracy and predicted deflection of 3%, actual deflection would be between 2% and 4%.

Note: Values applicable only for fills less than 50 ft. (15m). Table does not include any safety factor. For use in prediction initial deflections only, appropriate Deflection Lag Factor must be applied for long-term deflections. If bedding falls on the borderline between two compaction categories, select lower E' value or average the two values. Percentage Proctor based on laboratory maximum dry density from test standards using about 12,500 ft-lb/cu ft. (598,000 J/m^3) (ASTM D 698, AASHTO T-99, USBR Designation E-11). 1 psi = 6.9 kPa.

SOURCE: "Soil Reaction for Buried Flexible Pipe" by Amster K. Howard, U.S. Bureau of Reclamation, Denver, Colorado. Reprinted with permission from American Society of Civil Engineers.

d. Bedding Constant, *K*

The bedding constant is a term which accounts for the reactive force imparted from the pipe bedding material when a pipe is installed. The bedding constant is determined from the bedding angle which is described in Figure 1. When a harder bedding material is used, the pipe penetrates less which results in a smaller bedding angle. A preferred bedding material would be an easily consolidated material which would yield to the pipe when installed. Materials with small bedding angles close to zero are not recommended for pipe installation.

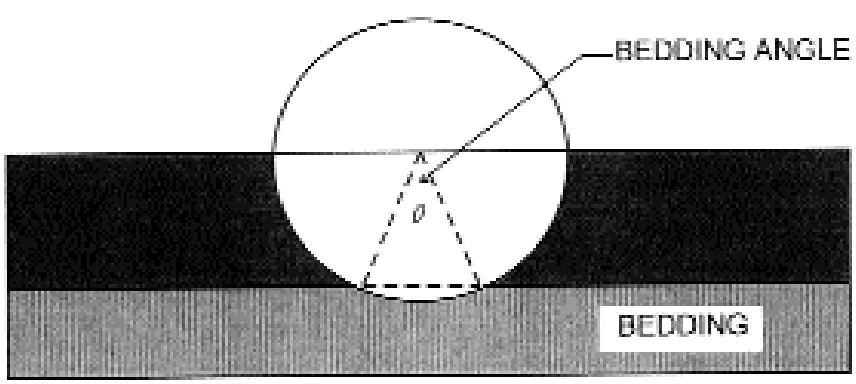
Table 3 gives a list of bedding angles and the appropriate constants. The range of the bedding constants in Table 3 is relatively small and is assumed to be equal to 0.1 for most installations.

TABLE 3

Values of Bedding Constant, K

Bedding Angle (Degrees)	K
0	0.110
30	0.108
45	0.105
60	0.102
90	0.096
120	0.090
180	0.083

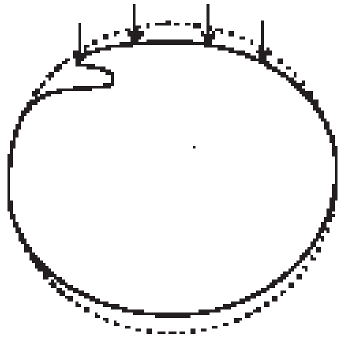
Figure 1



3. Pipe Buckling

Pipe buckling is a localized failure of the pipe wall structure which results from insufficient pipe stiffness for an application. Pipe buckling becomes significant in installations with deep burial, high groundwater, internal vacuums, or poor backfill conditions. There are two types of buckling pressures which can be checked for, unconfined and confined. Figure 2 shows a typical pipe buckling failure.

Figure 2
Localized Wall Buckling



a. Unconfined Buckling, P_{cr}

The unconfined buckling pressure neglects the support from the shear strength of the soil structure around the flexible pipe. The unconfined buckling pressure is used for hydrostatic conditions, where only pressure from a liquid is applied. Typical applications for unconfined buckling include underwater river crossings, or when determining acceptable grouting pressures of liner pipes. The formula for determining the unconfined buckling pressure is:

$$P_{cr} = \frac{.447 \cdot PS}{(1 - v^2)}$$

P_{cr} = *Unconfined Buckling Pressure, lb/in*^{2}
PS = *Pipe Stiffness, lb/in*^{2}
v = *Poisson's Ratio*

- Poisson's ratio is .38 for PVC and should be provided by the pipe manufacturer.
- The maximum grouting pressure for a liner can be determined by applying a factor of safety to the unconfined buckling pressure. The factor of safety is normally in the range of 2.0 - 2.5. The equation to determine maximum allowable grouting pressure is:

$$P_{grout} = \frac{P_{cr}}{FS}$$

P_{grout} = *Maximum Grouting Pressure, lb/in*^{2}
P_{cr} = *Unconfined Buckling Pressure, lb/in*^{2}
FS = *Factor of Safety*

b. Confined Buckling Pressure, P_b

The confined buckling pressure accounts for the support from the soil surrounding the pipe by adding the soil modulus, *E*', as a factor to the unconfined buckling pressure. The confined buckling pressure can be used to determine the maximum height of cover by dividing the buckling pressure by the soil unit weight. The formula for determining the confined buckling pressure is:

$$P_b = 1.15\sqrt{P_{cr} \cdot E'}$$

P_b = Confined Buckling Pressure, lb/in^2
P_{cr} = Unconfined Buckling Pressure, lb/in^2
E' = Soil Modulus, lb/in^2

- The formula for determining the maximum height of cover is:

$$H = \frac{P_b}{\gamma} \cdot 144$$

H = Height of Cover, ft
P_b = Confined Buckling Pressure, lb/in^2
γ = Soil Unit Weight, lb/ft^3

b. Hydrostatic Buckling Pressure, P_h

The hydrostatic buckling pressure is the result of a static level of water being present above the pipe. The pressure must be checked when groundwater is known to be present above the pipe.

The force exerted by the water is assumed to be constant over the life of the pipe. The force is more critical than that of soil because water has no shear strength and therefore cannot support itself or develop soil arching.

- The method for determining the hydrostatic buckling pressure is similar to determining the confined buckling pressure except that unconfined buckling pressure is re-calculated using the long term modulus of elasticity. The long term modulus accounts for the constant nature of the hydrostatic pressure. The formula for determining hydrostatic buckling pressure is:

$$P_h = 1.15\sqrt{\left[\frac{.447 \cdot \left(\frac{6.71 \cdot E_{long} I}{r^3}\right)}{(1 - v^2)}\right] \cdot E'}$$

P_h = Hydrostatic Buckling Pressure, lb/in^2
E_{long} = Long Term Modulus, lb/in^2
v = Poisson's Ratio
I = Moment of Inertia, in^3
E' = Soil Modulus, lb/in^2

The formula for determining the maximum height of water is:

$$H_w = \frac{P_h}{\gamma_w} \cdot 144$$

H_w = *Height of Water, ft*
P_b = *Hydrostatic Buckling, lb/in^2*
γ_w = *Water Unit Weight, lb/ft^3*

4. Wall Crushing

As a result of research performed on metal pipe walls, a performance limit called wall crushing has been developed. The metal pipe research showed that metal pipe walls can crush under heavy loads at deflections under 20 percent when the surrounding soils are highly compacted. The metal pipe research led to a "Ring Compression Theory" by H.L. White and J.P. Layer which was proposed as a performance limit for flexible pipes. The wall crush limit is satisfied by calculating the compressive stress in the pipe as a result of the soil load and comparing it to the allowable stress for the flexible pipe. The formula for determining compressive stress is:

$$\sigma = \frac{T}{A}$$

σ = *Compressive Stress, lb/in^2*
T = *Wall Thrust, lb/in*
A = *Area of Pipe Wall, in^2/in*

The steps for meeting the wall crush criteria are as follows:

- Calculate the vertical soil pressure, P_y, (see Section 1,)
- Calculate the wall thrust, *T*,
- Calculate the wall area, *A*, and
- Calculate the pipe compressive stress and compare the value to the allowable material stress.

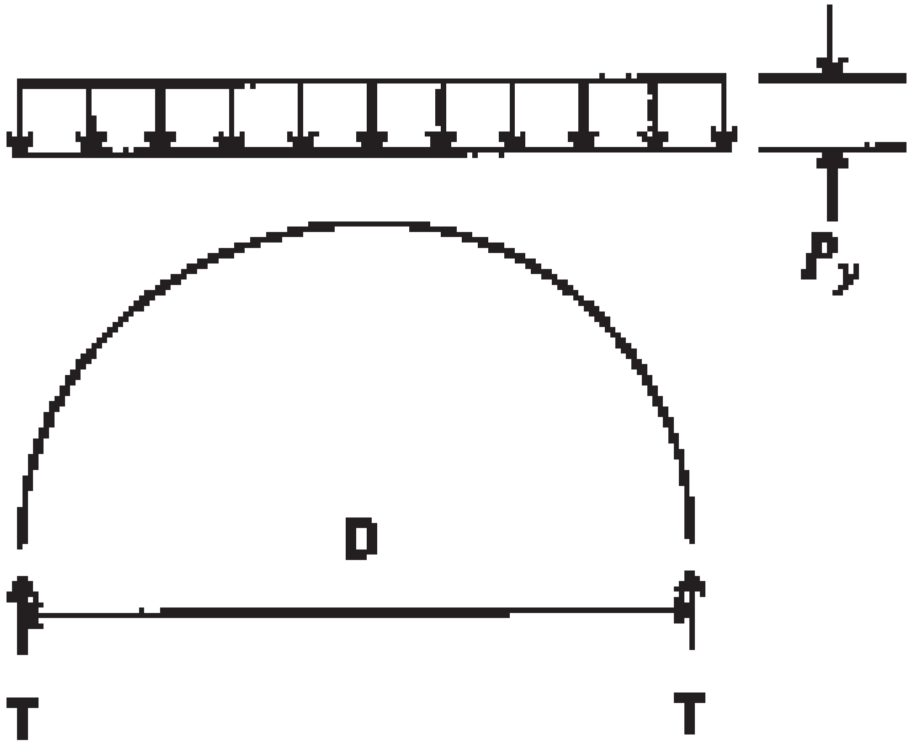
a. Wall Thrust, *T*

Wall thrust is the resultant force from the radial forces which are applied from the soil surrounding the flexible pipe (See Fig. 3). The formula for determining wall thrust is :

$$T = \frac{P_y \cdot D_0}{2}$$

T = *Wall Thrust, lb/in.*
P_y = *Vertical Soil Pressure, lb/in^2*
D_0 = *Outside Diameter, in*

Figure 3



b. Wall Area, *A*

The wall area is the cross-sectional area of the pipe wall per unit length. The pipe wall area of solid wall pipes is the thickness, and for profile pipes it is the cross-sectional area of the profile per unit length.

D. Pipe Flow Capacity

The determination of the flow capacity of a gravity flow pipe is normally calculated using an equation developed by Robert Manning in 1890. The Manning equation is based on open-channel flow and has been found to be reasonably accurate in determining gravity pipe flow.

The Manning equation is:

$$Q = \frac{1.49}{n} \; A \; R_h^{\frac{2}{3}} \; S_o^{\frac{1}{2}}$$

Q = Flow, ft^3/s
n = Manning Coefficient
A = Cross sectional flow area, ft^2
R_h = Hydraulic Radius, ft
S_o = Slope

The steps to determining pipe flow are as follows:

- Determine the Manning Coefficient, *n*
- Calculate the cross-sectional flow area,
- Calculate the hydraulic radius,
- Determine the slope, and
- Input values into Manning equation.

1. Manning Coefficient, *n*

The Manning coefficient is a value which is dependent on the surface roughness of the pipe material and has been experimentally determined for many materials. The Manning "n" is not a constant number and will vary depending on the specific pipe conditions. Table 4 provides a list of typical Manning "n" values to be used in the Manning equation.

2. Flow Area, A_{flow}

The flow area of a circular pipe is the cross-sectional area of the fluid flowing through the pipe. The calculation of the flow area becomes difficult for pipes which are not half full or full. A graph of the relationship between the percent depth and percent area has been developed to calculate the flow area. The formula for calculating the area of a full pipe is:

$$A_{full} = \pi \cdot r^2$$

The formula for calculating the area of a pipe which is not full is:

$$A_{flow} = \frac{A_{full} \cdot \%A}{100}$$

A_{flow} = Cross sectional Area of Flow, ft^2
A_{full} = Cross sectional Area of Pipe, ft^2
$\%A$ = Percent of Total Pipe Area

TABLE 4

Typical Manning "n" Values

Pipe Material	Pipe Condition		
	Installed	Mature	Deteriorated
Polyvinyl chloride (PVC) pipe	0.009	0.010	0.011
Smooth Wall HDPE	0.009	0.010	0.013
Corrugated HDPE			
12" - 15"	0.018	0.021	0.024
18" -36"	0.021	0.024	0.027
Vitrified Clay	0.013	0.015	0.017
Fiberglass	0.009	0.010	0.013
CIPP	0.009	0.010	0.013
Cement Mortar Lined Ducile Iron			
Uncoated Cast Iron Pipe	0.014	0.016	0.018
Coated Cast Iron Pipe	0.012	0.013	0.015
Corrugated Metal Pipe			
Annular Corrugations	0.024	0.027	0.031
15" Helical	0.013	0.015	0.017
18" Helical	0.015	0.018	0.021
24" Helical	0.018	0.021	0.024
36" Helical	0.021	0.024	0.027
Brick and Mortar	0.015	0.018	0.024
Concrete Pipe	0.013	0.015	0.018
Wood Stave Pipe	0.011	0.015	0.018

The procedure for calculating the area of a pipe not flowing full is:

a. Calculate the percent of depth, %*D*.

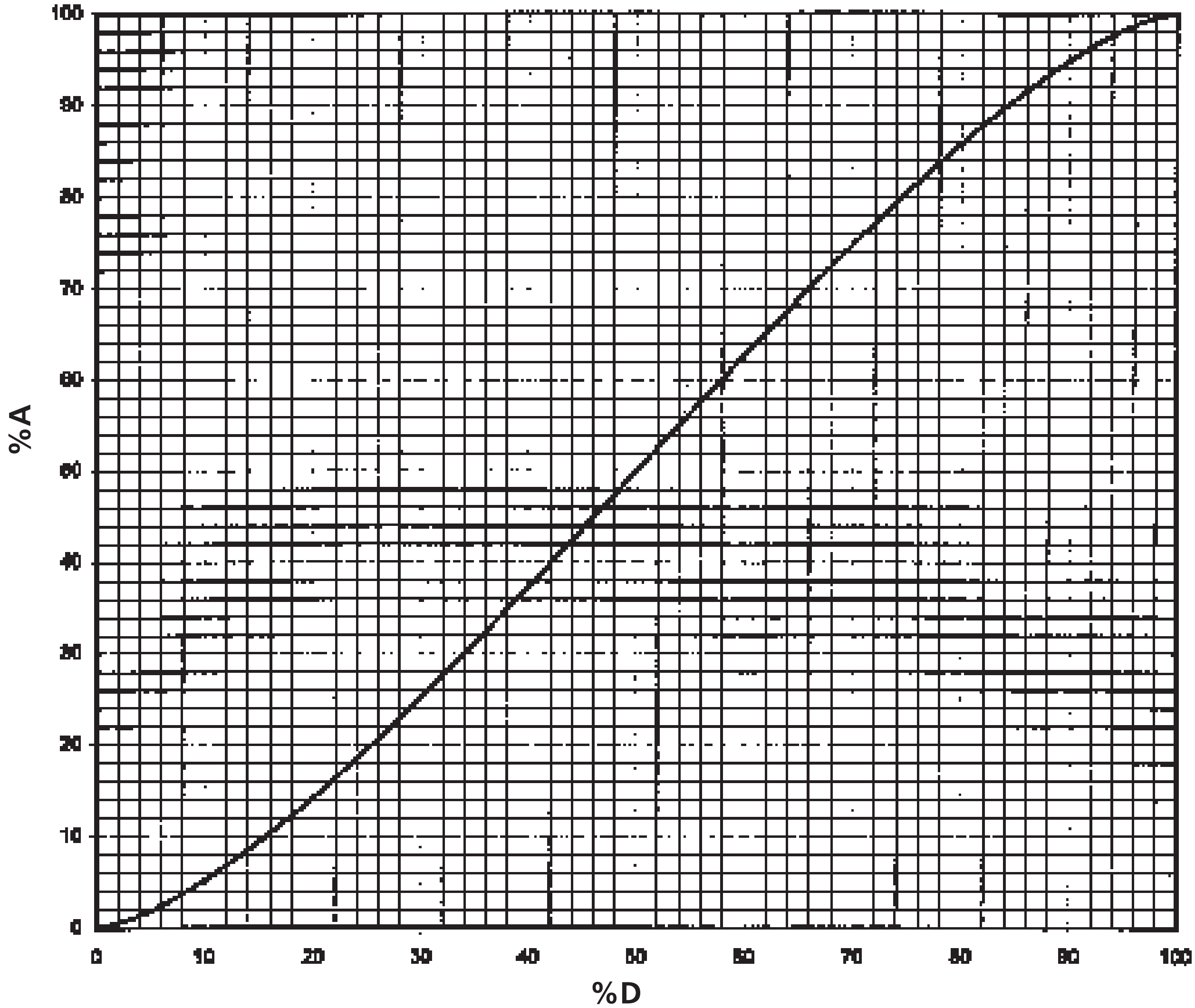
$$\%D = \frac{d}{D} \cdot 100$$

% D	= *Percent of Pipe Depth*
D	= *Pipe Inside Diameter, in*
d	= *Depth of Flow, in*

b. Determine the percent of pipe area from Figure 4 using percent depth, % *A*.

c. Calculate the flow area, A_{flow} .

Figure 4
% Area as a function of % Depth



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3. Hydraulic Radius, R_h

The hydraulic radius is a linear dimension developed to accommodate the noncircular cross sections of pipes not flowing full. The formula for the hydraulic radius is as follows:

$$R_h = \frac{A}{P_{wet}}$$

R_h = Hydraulic Radius, ft
A = Cross Sectional Area of Flow, ft^2 (See Section D 2)
P_{wet} = Wetted Perimeter, ft

Because of the difficulty in calculating the wetted perimeter of a pipe not flowing half or completely full, a graph has been developed relating the percent of total depth in a pipe to the percent of total perimeter. The hydraulic radius formula for a pipe flowing full is:

$$R_h = \frac{D}{4}$$

R_h = Hydraulic Radius, ft
D = Pipe Inside Diameter, ft

The procedure for determining the hydraulic radius for a pipe is:

a. Determine the percent of total depth, $\% D$.

$$\% D = \frac{d}{D} \cdot 100$$

$\% D$ = Percent of Pipe Depth
D = Pipe Diameter, in
d = Depth of Flow, in

b. Determine the percent of total perimeter from Figure 5 using the percent of total depth.

c. Calculate the wetted perimeter, P_{wet}:

$$P_{wet} = \frac{\pi \cdot D \cdot \% P}{100}$$

P_{wet} = Wetted Perimeter, ft
P_{total} = Total Pipe Perimeter, ft
$\% P$ = Percent of Pipe Perimeter

d. Solve for the hydraulic radius, R_h.

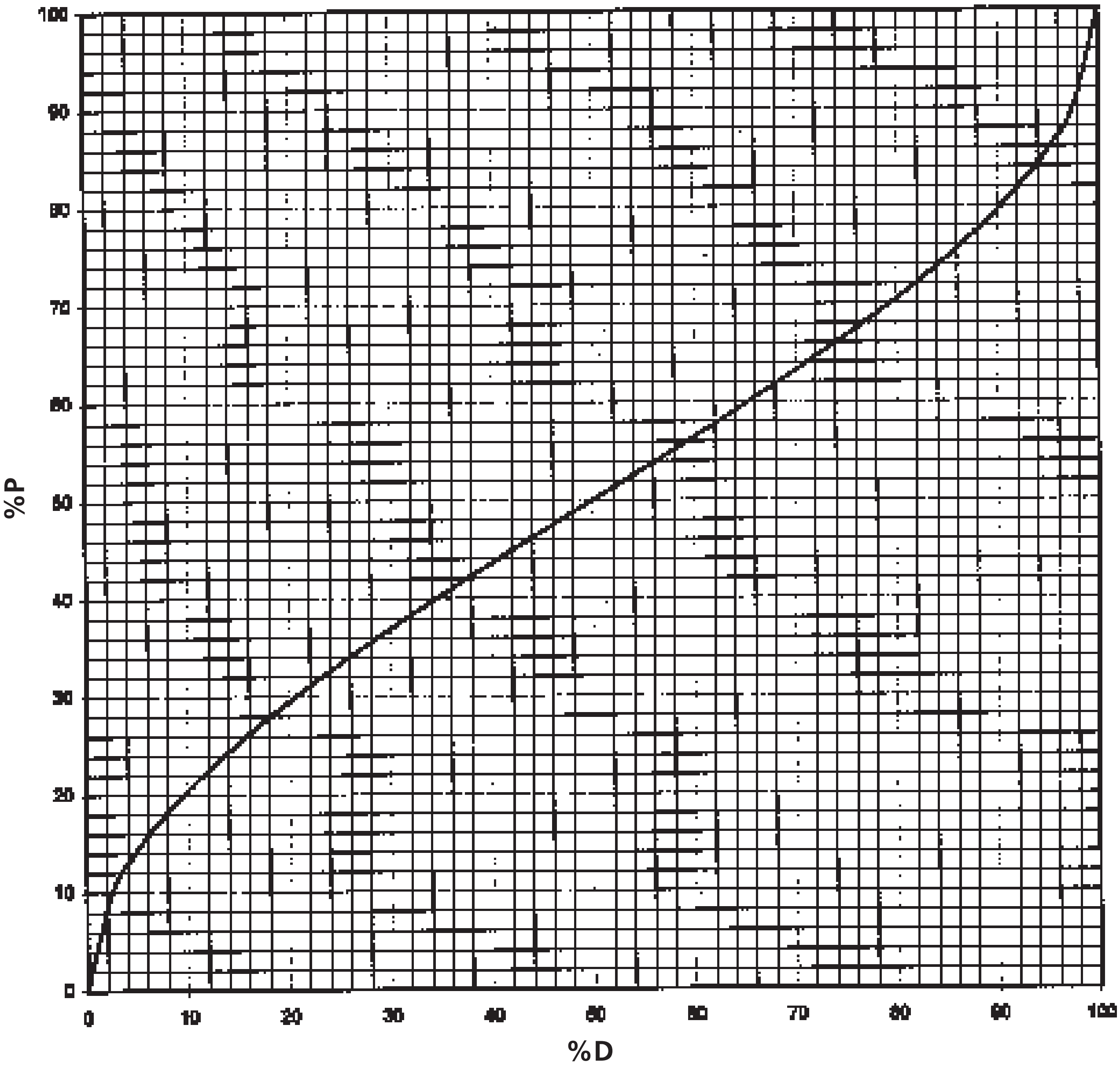
4. Pipe Slope, S

The pipe slope is the rise over run of a pipeline. The slope is calculated by determining the difference in elevation of two fixed points in a pipeline and dividing by the distance between the points. The slope will influence the velocity of the fluid flowing in a pipeline, as the slope rises so does the velocity. The equation for determining the slope is as follows:

$$S = \frac{Elev._1 - Elev._2}{Dist._{12}}$$

Figure 5

% Perimeter as a function of % Depth



5. Flow Programs

The difficulties in calculating pipe flow have led to the development of various computer programs which calculate flow. The user inputs parameters such as pipe diameter, depth of flow, and pipe slope and the program calculates the flow and various other hydraulic parameters. One such flow program, is "Flowmaster" from Haestad Methods in Waterbury CT., 203-755-1666.

E. Vylon Pipe Properties

Product Name	Nominal Size (in)	Outside Diameter (in)	Insider Diameter (in)	Min. Pipe Stiffness (lb/in²)	Wall Area (in²)	Moment of Inertia (in⁴/in)	Mean Radius (in)	Poisson's Ratio	Modulus of Elasticity (lb/in²)	Long Term Modulus (lb/in²)
PS - 46	4	4.215	3.987	46	0.1140	0.0001	2.051	0.38	600,000	158,000
	6	6.275	5.953	46	0.1610	0.0003	3.057	0.38	600,000	158,000
	8	8.400	7.968	46	0.2160	0.0008	4.092	0.38	600,000	158,000
	10	10.500	9.960	46	0.2700	0.0016	5.115	0.38	600,000	158,000
	12	12.500	11.876	46	0.3120	0.0025	6.094	0.38	600,000	158,000
	15	15.300	14.514	46	0.3930	0.0051	7.454	0.38	600,000	158,000
	18	18.700	17.716	46	0.4920	0.0099	9.104	0.38	600,000	158,000
Insider	12	12.500	11.480	150	0.4700	0.0087	5.995	0.38	500,000	158,000
	15	15.300	14.242	115	0.4970	0.0102	7.386	0.38	500,000	158,000
	18	18.700	17.660	46	0.4990	0.0104	9.090	0.38	500,000	158,000
Vylon	21	22.290	20.750	46	0.3050	0.0190	10.760	0.38	500,000	158,000
	24	25.040	23.500	46	0.3466	0.0278	12.135	0.38	500,000	158,000
	27	28.232	26.500	46	0.3896	0.0399	13.683	0.38	500,000	158,000
	30	31.430	29.500	46	0.4335	0.0544	15.233	0.38	500,000	158,000
	36	37.800	35.500	46	0.5384	0.0949	18.325	0.38	500,000	158,000
	42	44.200	41.500	46	0.6100	0.1517	21.425	0.38	500,000	158,000
	48	50.570	47.500	46	0.7549	0.2304	24.518	0.38	500,000	158,000

F. Design Examples

1. Direct Bury Pipe

Perform the design for a 48" Vylon pipe buried under 35' of soil with a unit weight of 120 lb/ft^3. The native soil is coarse grained soil and the pipe will be bedded in crushed rock. The required live loading is H20.

Given:

Pipe Diameter	= 48 in.	*Depth of Cover*	= 35 ft
Soil Unit Weight	= 120 lb/ft^3	*Pipe Stiffness*	= 46 lb/in^2
Poisson's Ratio	= .38		

a. Calculate Deflection

- Calculate Dead Load

$$DL = \frac{\gamma \cdot H}{144}$$

DL = Dead Load, lb/in^2
γ = Soil Unit Weight, lb/ft^3
H = Height of Cover, ft

$$DL = \frac{120 \cdot 35}{144}$$

$$DL = \underline{29.17\ lb/in^2}$$

- Determine the Live Load

  Refer to Table 1: Live Loads on Flexible Pipe and lookup the H20 load for a 35' height of cover. The live load is negligible for this depth.

- Calculate the Total Pipe Load

  Because the live load is zero, the total load on the pipe is the dead load.

$$\underline{P_y = DL = 29.17\ lb/in^2}$$

- Set the Deflection Lag Factor to 1.0

  Using the prism load to calculate the dead load allows the deflection lag factor to be set to 1.0.

- Choose the *E*' Value from Table 2.

  Choose a value for a well compacted crushed stone from the table, conservatively choose *E*' = 1500.

- Set the Bedding Constant to .1

- Calculate Deflection

- Calculate Deflection

$$\Delta = \frac{D_L \cdot K \cdot P_y}{(.149 \cdot PS) + (0.061 \cdot E')} \cdot 100$$

Δ = Deflection, %
D_L = Deflection Lag Factor
K = Bedding Constant
P_y = Prism Load, lb/in^2
PS = Pipe Stiffness, lb/in^2
E' = Soil Modulus, lb/in^2

$$\Delta = \frac{1.0 \cdot .1 \cdot 29.17}{(.149 \cdot 46) + (0.061 \cdot 1500)} \cdot 100$$

$$\Delta = \underline{2.97\%}$$

b. Check Buckling Resistance

- Calculate the Unconfined Buckling Pressure

$$P_{cr} = \frac{.447 \cdot PS}{(1 - v^2)}$$

P_{cr} = Unconfined Buckling Pressure, lb/in^2
PS = Pipe Stiffness, lb/in^2
v = Poisson's Ratio

$$P_{cr} = \frac{.447 \cdot 46}{(1 - .38^2)}$$

$$P_{cr} = \underline{24.03\ lb/in^2}$$

- Calculate the Confined Buckling Pressure

$$P_b = 1.15\sqrt{P_{cr} \cdot E}$$

P_b = Confined Buckling Pressure, lb/in^2
P_{cr} = Unconfined Buckling Pressure, lb/in^2
E' = Soil Modulus, lb/in^2

$$P_b = 1.15\sqrt{24.03 \cdot 1500}$$

$$P_b = \underline{218.3\ lb/in^2}$$

- Calculate the Maximum Height of Cover

$$H = \frac{P_b}{\gamma} \cdot 144$$

H = Height of Cover, ft
P_b = Confined Buckling, lb/in^2
γ = Soil Unit Weight, lb/ft^3

$$H = \frac{218.3}{120} \cdot 144$$

$$H = \underline{262\ ft} > 35\ ft. \qquad OK$$

c. Check Wall Crush

- Calculate the Wall Thrust

$$T = \frac{P_y \cdot D_0}{2}$$

T = Wall Thrust, lb/in
P_y = Vertical Soil Pressure, lb/in^2
D_0 = Outside Diameter, in

$$T = \frac{29.17 \cdot 50.57}{2}$$

$$T = \underline{737.6\ lb/in}$$

- Determine the Wall Area

Section E gives typical Vylon properties, for 48" pipe the wall area is .7549.

- Calculate the Compressive Stress

$$\sigma = \frac{T}{A}$$

σ = Compressive Stress, lb/in^2
T = Wall Thrust, lb/in
A = Area of Pipe Wall, in^2/in

$$\sigma = \frac{737.6}{.7549}$$

$$\sigma = \underline{977\ lb/in^2} < 2900\ lb/in^2 \qquad OK$$

2. Slipliner Pipe

Perform the design for a 42" Vylon Slipliner pipe installed under 30' of soil with a unit weight of 120 pcf. The required live loading is H20. Assume the soil is completely saturated. The annular space will be grouted with a 55 lb. grout at 4 psi.

Given:

Pipe Diameter	= 42 in	*Depth of Cover*	= 30 ft
Soil Unit Weight	= 120 lb/ft^3	*Pipe Stiffness*	= 46 lb/in^2
Poisson's Ratio	= .38	*Water Level*	= 30 ft
Grouting Pressure	= 4 lb/in^2	*Grout Weight*	= 55 lb/ft^3
Long Term Modulus	= 158,000 lb/in^2	*Moment of Inertia*	=.1517 in^3

a. Calculate Deflection

- Calculate Dead Load

$$DL = \frac{\gamma \cdot H}{144}$$

DL = Dead Load, lb/in^2
γ = Soil Unit Weight, lb/ft^3
H = Height of Cover, ft

$$DL = \frac{120 \cdot 30}{144}$$

$$DL = \underline{25\ lb/in^2}$$

- Determine the Live Load

Refer to Table 1: Live Loads on Flexible Pipe and lookup the H20 load for a 30' height of cover. The live load is negligible for this depth.

- Calculate the Total Pipe Load

Because the live load is zero, the total load on the pipe is the dead load.

$$P_y = DL = \underline{25\ lb/in^2}$$

- Set the Deflection Lag Factor to 1.0

Using the prism load to calculate the dead load allows the deflection lag factor to be set to 1.0.

- Choose the E' value from Table 2.

The surrounding soil in the case of a Slipliner installation is a grout, which is considered a stiff soil, to be conservative use E' = 1500.

- Set the bedding constant to .1

- Calculate Deflection

$$\Delta = \frac{D_L \cdot K \cdot P_y}{(.149 \cdot 46) + (0.061 \cdot E')} \cdot 100$$

Δ = *Deflection, %*
D_L = *Deflection Lag Factor*
K = *Bedding Constant*
P_y = *Prism Load, lb/in^2*
PS = *Pipe Stiffness, lb/in^2*
E' = *Soil Modulus, lb/in^2*

$$\Delta = \frac{1.0 \cdot .1 \cdot 25}{(.149 \cdot 46) + (0.061 \cdot 1500)} \cdot 100$$

$$\Delta = \underline{2.54}\%$$

b. Check Buckling Resistance

- Calculate the Unconfined Buckling Pressure

$$P_{cr} = \frac{.447 \cdot PS}{(1 - v^2)}$$

P_{cr} = *Unconfined Buckling Pressure, lb/in^2*
PS = *Pipe Stiffness, lb/in^2*
v = *Poisson's Ratio*

$$P_{cr} = \frac{.447 \cdot 46}{(1 - .38^2)}$$

$$P_{cr} = \underline{24.03 \text{ lb/in}^2}$$

- Calculate the Maximum Allowable Grouting Pressure

Apply a factor of safety of 2.5 to the unconfined buckling pressure to determine the maximum allowable grouting pressure.

$$P_{grout} = \frac{P_{cr}}{FS}$$

P_{grout} = *Maximum Grouting Pressure, lb/in^2*
P_{cr} = *Unconfined Buckling Pressure, lb/in^2*
FS = *Factor of Safety*

$$P_{grout} = \frac{24.03}{2.5}$$

$$P_{grout} = \underline{9.6 \text{ lb/in}^2} > 4 \text{ lb/in}^2$$

c. Calculate the Confined Buckling Pressure

$$P_b = 1.15\sqrt{P_{cr} \cdot E'}$$

P_b = Confined Buckling Pressure, lb/in^2
P_{cr} = Unconfined Buckling Pressure, lb/in^2
E' = Soil Modulus, lb/in^2

$$P_b = 1.15\sqrt{24.03 \cdot 1500}$$

$$P_b = \underline{218.3\ lb/in^2}$$

- Calculate the Maximum Height of Cover

$$H = \frac{P_b}{\gamma} \cdot 144$$

H = Height of Cover, ft
P_b = Confined Buckling Pressure, lb/in^2
γ = Soil Unit Weight, lb/ft^3

$$H = \frac{218.3}{120} \cdot 144$$

$$H = \underline{262\ ft} > 30\ ft.$$

d. Calculate the Hydrostatic Buckling Pressure

$$P_h = 1.15\sqrt{\left[\frac{.447 \cdot \left(\frac{6.71 \cdot E_{long} I}{r^3}\right)}{(1 - v^2)}\right] \cdot E'}$$

$$P_h = 1.15\sqrt{\left[\frac{.447 \cdot \left(\frac{6.71 \cdot 158{,}000 \cdot .1517}{21.425^3}\right)}{(1 - .38^2)}\right] \cdot 1500}$$

$$P_h = \underline{130.19\ lb/in^2}$$

- Calculate the maximum height of water

$$H_w = \frac{P_h}{\gamma_w} \cdot 144$$

H_w = *Height of Water, ft*
P_b = *Hydrostatic Buckling, lb/in²*
γ_w = *Water Unit Weight, lb/ft³*

$$H = \frac{130.19}{62.4} \cdot 144$$

$$H_w = \underline{300.4\ ft}$$

e. Check Wall Crush

- Calculate the Wall Thrust

$$T = \frac{P_y \cdot D_0}{2}$$

T = *Wall Thrust, lb/in*
P_y = *Vertical Soil Pressure, lb/in²*
D_0 = *Outside Diameter, in*

$$T = \frac{25 \cdot 44.2}{2}$$

$$T = \underline{552.5\ lb/in}$$

- Determine the wall area

Section E gives typical Vylon properties, for 42" pipe the wall area is .61.

- Calculate the Compressive Stress

$$\sigma = \frac{T}{A}$$

σ = *Compressive Stress, lb/in²*
T = *Wall Thrust, lb/in*
A = *Area of Pipe Wall, in²/in*

$$\sigma = \frac{552.5}{.61}$$

$$\sigma = \underline{905.7\ lb/in^2} < 2900\ lb/in^2$$

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