Section Two: Steel Pipe Design

AMERICAN
SPIRALWELD PIPE
THE RIGHT WAY

AMERICAN SpiralWeld Pipe Company, LLC (AMERICAN), located in Columbia, South Carolina, manufactures the highest quality spiral-welded steel pipe available (see Section 1 – Introduction for more detail). In a 290,000 square-foot production facility equipped with the latest technology, AMERICAN produces the pipe to meet or exceed the requirements of applicable American Water Works Association (AWWA) and American Society for Testing and Materials (ASTM) standards. The inherent properties of the steel from which spiral-welded pipe is formed result in a strong and adaptable product. It is important that the designer understands these properties and how they affect the design of steel pipe.

Steel - Mechanical Properties

Modern steel making processes have resulted in excellent grain structure and control of the mechanical properties. These properties include minimum yield strength, minimum tensile strength, elongation (measure of ductility), impact strength, and hardness. AMERICAN is capable of forming spiral-welded steel pipe from steel that has a maximum yield strength up to 70 ksi. However, for typical water and wastewater applications, minimum yield strengths between 35 ksi and 52 ksi are more common. This flexibility offers customers an ability to optimize pressure and structural capabilities.

Steel – Benefits

Some benefits of steel pipe include material properties; adaptability to different applications such as water and wastewater transmission, pump station and treatment plant piping, circulating water lines for the power industry, penstocks, intakes and outfalls, aerial crossings, aqueducts, and trenchless; flexibility of flow and pressures by varying sizes and wall thicknesses; and the ability to provide a simple basis for design.

Design Overview

The basic criterion for the design of a steel pipe is resistance to internal pressure. Once that criterion has been met, the resulting wall thickness is verified for adequacy with respect to other performance criteria such as:

- External loads
- Handling
- Buckling (external pressure)

For many projects, the wall thickness recommended to allow reasonable handling of the pipe satisfies the remaining performance criteria as well. *AWWA Manual M11, Steel Water Pipe: A Guide for Design and Installation*, and American Iron and Steel Institute's *Welded Steel Pipe Design Manual* provide excellent information for the design professional.

General Principles

Typically, water pipe should be designed based on the internal working and transient pressure service conditions to which it will be subjected during its lifetime. Additional service conditions to evaluate include external operating and transient or live load, and vacuum pressures. In addition, adequate stiffness is needed for ease of handling pipe in the facility and in the field. The following guidelines focus on the design and calculation of the required pipe wall thickness based on these service conditions.

Most plate and sheet manufacturers today produce very high quality steel using the continuous casting process. This process yields a fine grain, "killed" (deoxidized) steel that is metallurgically homogeneous and exhibits excellent ductility. Steel pipe is typically manufactured from one of several steels available in varying strengths as listed in Table **2.1**. Typically, higher strength steel has a marginally higher cost. For applications where the operating or design pressure exceeds 175 psi (1.1 MPa), an analysis should be performed to evaluate the potential cost or other advantages of using steel with yield strength in excess of 42 ksi (290 MPa). For the same pressure requirements, the increase in cost for using a higher strength material is typically less than the costs associated with the increased wall thickness required for a lesser strength steel. The use of higher strength steel normally has little benefit, though, for lower pressure, buried applications. In low-pressure designs, handling or other considerations — rather than internal pressure — will most often govern the selection of the pipe wall thickness.

Table 2.1

ASTM Material Designation[1]	Grade	Minimum Yield Strength ksi (MPa)	Minimum Tensile Strength ksi (MPa)
		Steel Sheet (Coil or Flat)	
A139	B	35 (242)	60 (415)
	C	42 (290)	60 (415)
	D	46 (315)	60 (415)
	E	52 (360)	66 (455)
		Steel Plate	
A36/A36M		36 (248)	58 (400)
A572/A572M	42	42 (290)	60 (415)
	50	50 (345)	65 (449)
A516/A516M	55	30 (205)	55 (380)
	60	32 (220)	60 (415)
	65	35 (240)	65 (450)
	70	38 (260)	70 (485)

[1]Other steel material types, including various grades of ASTM A1011 or ASTM A1018, are available upon request. Contact an AMERICAN representative for availability of a particular steel material type not listed above.

When designing a steel pipe, the main design consideration is the pipe's ability to withstand internal pressure. After a wall thickness has been determined based on internal pressure, including both operating and transient pressures, that thickness must be checked to determine its adequacy for resisting external loads and the minimum thickness required for handling. External loads include those due to backfill material and potential vehicles, construction equipment, or railroad cars, and buckling forces resulting from external pressure. As required, the composite wall thickness for non-buried pipe (steel thickness plus cement lining thickness, when applicable) can be increased; or, for buried steel pipe, the stiffness of the pipe/backfill system can be increased to resist the external loads. The most common and cost effective method used to increase the pipe/backfill system stiffness is to improve the quality of the backfill material and/or the level of backfill compaction.

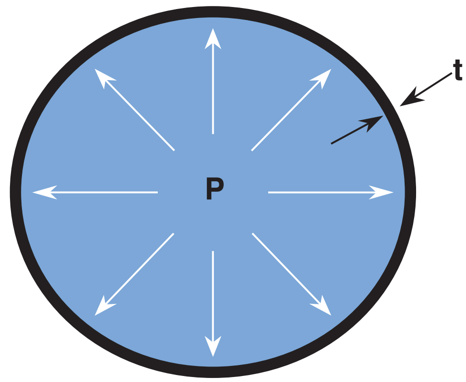
Internal Pressure

Design for internal pressure requires a two-part stress analysis. Each part of the analysis is governed by the application of the Barlow hoop stress formula, reconfigured as follows:

t = PD/2S

Where:

t = minimum, nominal specified wall thickness, in. (mm)
P = pressure, psi (MPa)
D = steel cylinder outside diameter*, in. (mm)
S = allowable design stress psi, (MPa)



*Note: Use of the outside diameter is a conservative design approach.

The wall thickness should first be calculated based on the maximum sustained internal operating (working) pressure, and then calculated based on the larger of the maximum sustained operating plus transient pressure, or the field-test pressure. As noted in the AWWA Manual M11, when calculating thickness due to the operating pressure, the design stress should be limited to 50% of the minimum yield strength of the steel. In addition, when calculating thickness due to the operating plus transient, or test pressure, the design stress should be limited to 75% of the minimum yield strength of the steel.

Handling

For pipe with shop-applied cement mortar lining, the minimum required wall thickness based on handling should be limited by a D_n/t (nominal diameter/thickness) ratio of 240. For pipe with a spray-applied flexible lining or no lining at all, the minimum required wall thickness based on handling should be limited by a D_n/t ratio of 288.

Cement mortar lined pipe: $D_n/t = 240$

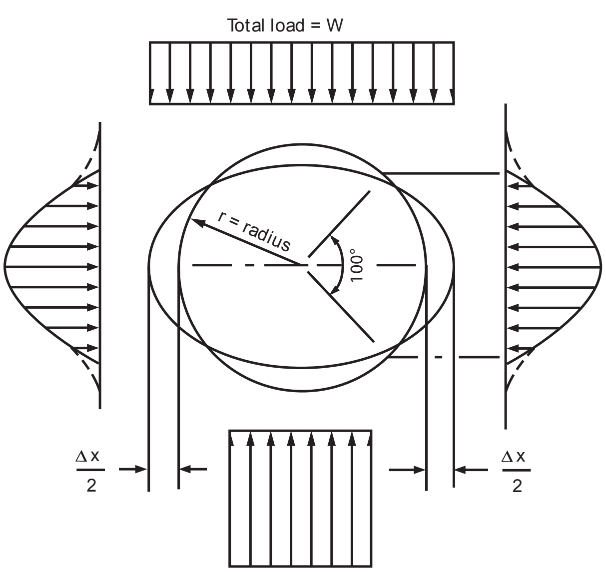
Spray-applied flexible lining or bare pipe: $D_n/t = 288$

External Loading

For buried pipe, resistance to external loading is a function of pipe stiffness and passive soil resistance under and adjacent to the pipe. These two factors work in unison to create a pipe/backfill system whose stiffness resists the earth and live loads to which the pipe is subjected. The estimated horizontal deflection of a buried pipe can be calculated by the Iowa deflection formula, as follows:

$$\Delta_x = \frac{D_l K W r^3}{EI + 0.061E' r^3}$$

Where:
- Δ_x = horizontal deflection of pipe, in. (mm)
- D_l = deflection lag factor
- K = bedding constant
- W = external load per unit length of pipe ($W_E + W_L$), lb/in. (N/mm)
  - Where: W_E = earth load (dead load)
  - W_L = live load
- r = mean radius of pipe shell, in. (mm)
- EI = pipe wall stiffness, in-lb (mm-N)*
  - Where: E = modulus of elasticity [$30\text{x}10^6$ psi ($207\text{x}10^3$ MPa) for steel and $4\text{x}10^6$ psi ($27.6\text{x}10^3$ MPa) for cement mortar]
  - I = transverse moment of inertia per unit length of pipe wall, in.^{3} (mm^3)
- E' = modulus of soil reaction, lb/in.^{2} (N/mm^2)



*Under load, the individual components of the pipe wall (steel, mortar lining and, when applicable, mortar coating) act together as laminated rings. The combined action of these elements increases the overall moment of inertia of the pipe, over that of the steel cylinder alone. The total stiffness, EI, is equal to the sum of all individual values: $E_sI_s + E_lI_l + E_cI_c$.

As noted above, the stiffness of the pipe/backfill system – pipe stiffness and passive soil resistance of the backfill – plays the key role in predicting deflection. The system is the denominator of the Iowa deflection equation, where pipe stiffness is the EI term and passive soil resistance of the backfill is the $0.061E'r^3$ term. History has shown that, in general, the most effective improvement in the system's ability to resist loading comes from increasing the passive soil resistance of the backfill and not the pipe stiffness. When the calculated deflection exceeds the allowable, improvement of the backfill material or level of compaction should be the prime consideration versus an increase of the steel wall thickness. Following are explanations of the terms used in the equation above.

Δ_x, Predicted Deflection – Because steel pipe is designed as a flexible conduit, significant deflection can occur without damaging the product. Common practice has limited the calculated deflection to 5%, although larger deflections may not affect pipe performance. Deflection limitations are a function of the rigidity of the specific lining and coating being used. For spray-applied flexible linings and flexible coatings, AWWA M11 recommends a maximum allowable deflection of 5%. The AWWA recommendation for cement mortar lined pipe with a flexible coating is 3%. To limit coating cracks in a cement mortar coated pipe, AWWA recommends limiting deflection to 2%. A deflection limitation of 2% is also generally recommended for a field applied cement mortar lining due to lining equipment limitations.

In summary:
Cement Mortar Lining x Cement Mortar Coating = 2% of pipe diameter
Cement Mortar Lining x Flexible Coating = 3% of pipe diameter
Flexible Lining x Flexible Coating = 5% of pipe diameter

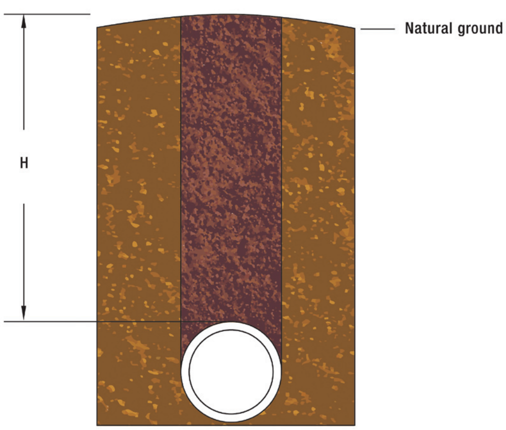
D_l, Deflection Lag Factor – The deflection lag factor is a subjective multiplier used to define the projected long-term deflection of a pipe as a function of the calculated deflection at time of installation. With a well compacted backfill around the pipe cylinder, it is common practice to use a factor of 1.0. This is especially true for a pressurized pipe, as the internal pressure will tend to round the pipe while in service. As a result, additional settling of the backfill over time will improve the material consolidation around a circular cylinder. This improvement in consolidation will increase, not decrease, the system's capacity to resist external load.

K, Bedding Constant – The bedding constant is a reflection of the influence of the bedding angle on the pipe's resistance to external load. (The bedding angle is a measurement in degrees of the circumferential contact of the bottom of the pipe with the trench bedding material.) With improved bedding below the springline (50% of pipe outside diameter), support to the pipe is improved resulting in decreased deflection. The range of **K** is from 0.110 for pipe laid on a flat trench bottom (no bedding) to 0.083 for the pipe bedded to the springline. For typical conditions encountered with the installation of steel pipe, a conservative design value of **K** is 0.10.

W_E, Earth Load (Dead Load) – When buried in an embankment or wide trench, the settlement ratio for a flexible conduit such as steel pipe is assumed to be zero. As such, the prism of soil directly over the pipe is used as the resultant earth load. The prism dimensions are represented as a width equal to the pipe outside diameter, a height equal to the depth of cover over the top of the pipe, and a unit length of 1 in. This method is conservative as no consideration is given to potential arching action of the backfill material relative to the adjacent native soil. A conservative density of the backfill material, γ_E, is typically taken as 120 lb/ft^3 for determination of the earth load.

W_L, Live Load – Live loads are typically a result of vehicle wheels, equipment wheels or tracks, or railroad car wheels. The accepted values for vehicle and railroad induced live loads (standard HS-20 highway and E-80 railroad loading) are listed in **Table 2.2**. If present, live loads resulting from movement of heavy equipment over pipelines must be given special consideration. For extreme loading conditions reference: Spangler, M.G. & Handy, R.L., *Soil Engineering*, Harper & Row, Publishers, New York, NY (4th ed., 1982); or contact AMERICAN.

EI, Pipe Stiffness – As noted previously, the pipe stiffness EI is equal to the sum of all individual stiffness values for each of the laminar rings of the pipe structure; that is E_sI_s plus E_lI_l plus E_cI_c, for the cylinder, cement mortar lining, and cement mortar coating respectively. The stiffness of each of the rings is calculated using the modulus of elasticity of the component, in psi, and the moment of inertia as a per unit length value, defined as $t^3/12$.



E′, Modulus of Soil Reaction – The modulus of soil reaction is an empirical measurement of a given compacted soil's resistance to movement. Modification of the value of E′, accomplished by improving the backfill material and/or improving the level of compaction, is the most common and most cost effective way to improve the stiffness of the pipe/backfill system. In recent years, designers have taken note of the inherent increase in the E′ value relative to increased depth of cover. Most notably, James D. Hartley and James M. Duncan of the University of California, Berkeley, published *Evaluation of the Modulus of Soil Reaction, E′, and Its Variation with Depth*. Their research defined E′ as a function of soil type, degree of compaction, and depth of cover, H, as shown below. Their results are listed in **Table 2.3**.

Table 2.2

Highway HS-20 Loading		Railroad E-80 Loading	
Height of Cover (ft)	Load (psi)	Height of Cover (ft)	Load (psi)
1	12.5	2	26.4
2	5.6	5	16.7
3	4.2	8	11.1
4	2.8	10	7.6
5	1.7	12	5.6
6	1.4	15	4.2
7	1.2	20	2.1
8	0.7	30	0.7

For extreme loading conditions reference: Spangler, M.G. & Handy, R.L., *Soil Engineering*, Harper & Row, Publishers, New York, NY (4th ed., 1982).

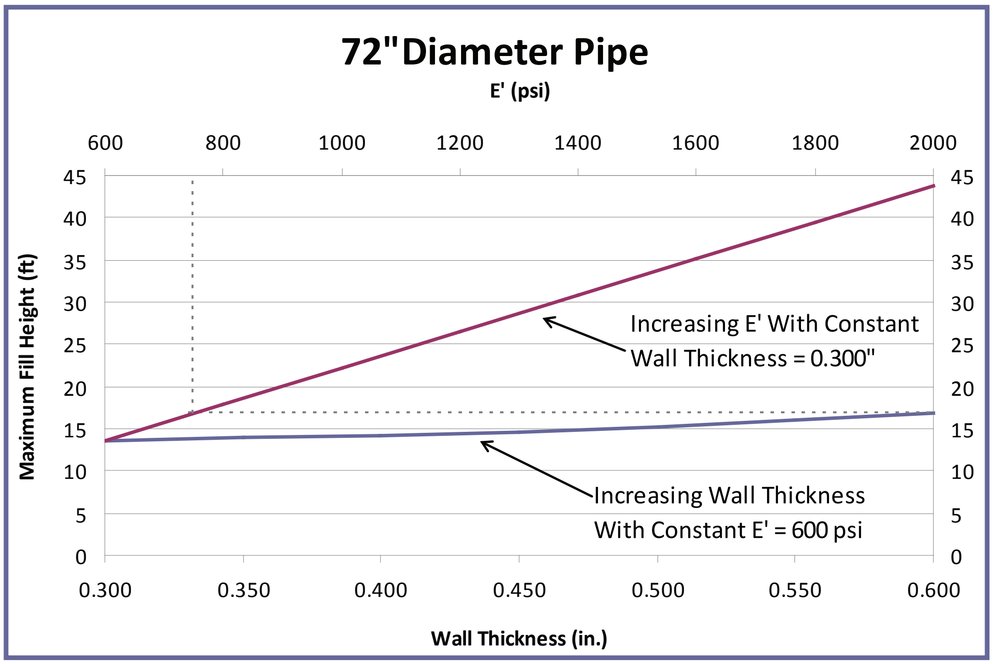
Table 2.3

E′, Modulus of Soil Reaction psi					
		Standard AASHTO Relative Compaction			
Type of Soil	Depth of Cover (ft)	85%	90%	95%	100%
Fine-grain soils with less than 25% sand content (CL, ML, CL-ML)	0-5	500	700	1,000	1,500
	5-10	600	1,000	1,400	2,000
	10-15	700	1,200	1,600	2,300
	15-20	800	1,300	1,800	2,600
Coarse-grained soil with fines (SM, SC)	0-5	600	1,000	1,200	1,900
	5-10	900	1,400	1,800	2,700
	10-15	1,100	1,700	2,300	3,300
	15-20	1,300	2,000	2,700	3,800
Coarse-grained soil with little or no fines (SP, SW, GP, GW)	0-5	700	1,000	1,600	2,500
	5-10	1,000	1,500	2,200	3,300
	10-15	1,050	1,600	2,400	3,600
	15-20	1,100	1,700	2,500	3,800
Crushed stone*	na	3,000	3,000	3,000	3,000

*Crushed stone not included in Hartley-Duncan, E′ of 3,000 psi minimum as determined by U.S. Bureau of Reclamation. This value is extremely conservative as values from 7,000 to 16,000 psi have been witnessed in practice.

As compaction of the backfill material is the single most important factor in developing resistance to external loads for the pipe, a minimum AASHTO Standard relative compaction of 85% is recommended for all steel pipe installations.

The relationship between increased compaction and increased E′ shown in **Table 2.3** provides the designer the information necessary to evaluate the most economical requirements for a given project. The significant effect that improved embedment (increased E′) plays in pipe's ability to resist external load is easily shown by performing several deflection analyses. Results of such analyses for one pipe size are depicted graphically in the figure below, where evaluations of maximum fill height for varying wall thickness (constant E′) have been plotted with evaluations of maximum fill height for varying E′ (constant wall thickness).



Calculations for the figure were based on the following: ASTM A139, Grade C steel with a stiffness based on D/t = 240, minimum yield (Sy) of 42 ksi, allowable deflection (t::x) of 3.00%, deflection lag factor (D_l) of 1.0, bedding constant (K) of 0.10, and a soil density (γ_E) of 120 lb/ft³. The composite EI of the steel cylinder and the C205 cement mortar lining was used in all deflection calculations.

The dotted lines in the above figure highlight that an increase in initial E′ value of less than 200 psi provides the same effective increase in allowable fill height as would be achieved by doubling the initial wall thickness of the steel cylinder. This effect is the same for any pipe of similar stiffness (D/t = 240) as that shown in the figure. An obvious conclusion that can be drawn from this figure is that there is no economic justification for increasing the steel thickness to enable the pipe/backfill system to accept additional cover. The appropriate approach is to increase the quality of the soil embedment envelope.

External Pressure or Vacuum

ABOVE GROUND OR SUBAQUEOUS UNBURIED INSTALLATION

When pipelines are installed above ground, and the pipe is subject to vacuum, the wall thickness must be designed to withstand collapse due to the vacuum. Analysis should be based on the pipe functioning in the open atmosphere, absent of support from any backfill material. The collapsing pressure should be determined based on an adaptation of Timoshenko's theory for collapse of a round steel pipe, as follows:

$$P_c = 2E_s(t_s/d_n)^3/(1-\nu_s^2) + 2E_l(t_l/d_n)^3/(1-\nu_l^2) + 2E_c(t_c/d_n)^3/(1-\nu_c^2)$$

Where:

P_c	=	collapsing pressure, psi (MPa)
t_s	=	steel cylinder wall thickness, in. (mm)
t_l	=	cement lining thickness, in. (mm)
t_c	=	cement coating thickness, in. (mm)
d_n	=	diameter to neutral axis of shell, in. (mm)
E_s	=	modulus of elasticity for steel, $30\text{x}10^6$ psi ($207\text{x}10^3$ MPa)
E_l & E_c	=	modulus of elasticity for cement mortar, $4\text{x}10^6$ psi ($27.6\text{x}10^3$ MPa)
ν_s	=	Poisson's ratio for steel 0.30
ν_l & ν_c	=	Poisson's ratio for cement mortar 0.25

BURIED INSTALLATION

History has shown that buried pipelines supported by a well-compacted, granular backfill will not buckle due to vacuum. When confirmation of this stability is desired, analysis of the external loads relative to the pipe stiffness can be performed. The sum of external loads should be less than or equal to the pipe's allowable buckling pressure, q_a, which is determined by the following:

$$q_a = (1/FS)(32R_wB'E'(EI/D^3))^{1/2}$$

Where: q_a = allowable buckling pressure, psi
FS = design factor = 2.0
R_w = water buoyancy factor
= $1-0.33(h_w/H)$, $0 \leq h_w \leq H$, but not <0.67
where H = height of fill over pipe, ft
h_w = height of water over pipe, ft
B′ = empirical coefficient of elastic support, dimensionless
$= \dfrac{1}{1 + 4e^{(-.065H)}}$
E′ = modulus of soil reaction, psi
EI = pipe wall stiffness, in-lb*
where E = modulus of elasticity ($30x10^6$ psi for steel and $4x10^6$ psi for cement mortar)
I = transverse moment of inertia per unit length of pipe wall, in.^{3}
D = outside diameter, in.

*Under load, the individual components of the pipe wall (steel, mortar lining and, when applicable, mortar coating) act together as laminated rings. The combined action of these elements increases the overall moment of inertia of the pipe, over that of the steel cylinder alone. The total stiffness, EI, is equal to the sum of all individual values: $E_sI_s + E_lI_l + E_cI_c$.

To determine the external loads on a pipe, the following equation applies:

$$\gamma_w h_w + R_w W_c/D + P_v \leq q_a$$

Where: q_a = allowable buckling pressure, psi
γ_w = specific weight of water (0.0361 lb/in.^{3})
h_w = height of water above pipe, in.
R_w = water buoyancy factor
W_c = vertical soil load on pipe per unit length, lb/in.
D = outside diameter, in.
P_v = internal vacuum pressure, psi

At times, live loads may need to be addressed when analyzing potential buckling. Simultaneous application of both live loads and internal vacuum are not normally considered. When addressing live loads, the following equation applies:

$$\gamma_w h_w + R_w W_c/D + W_L/D \leq q_a$$

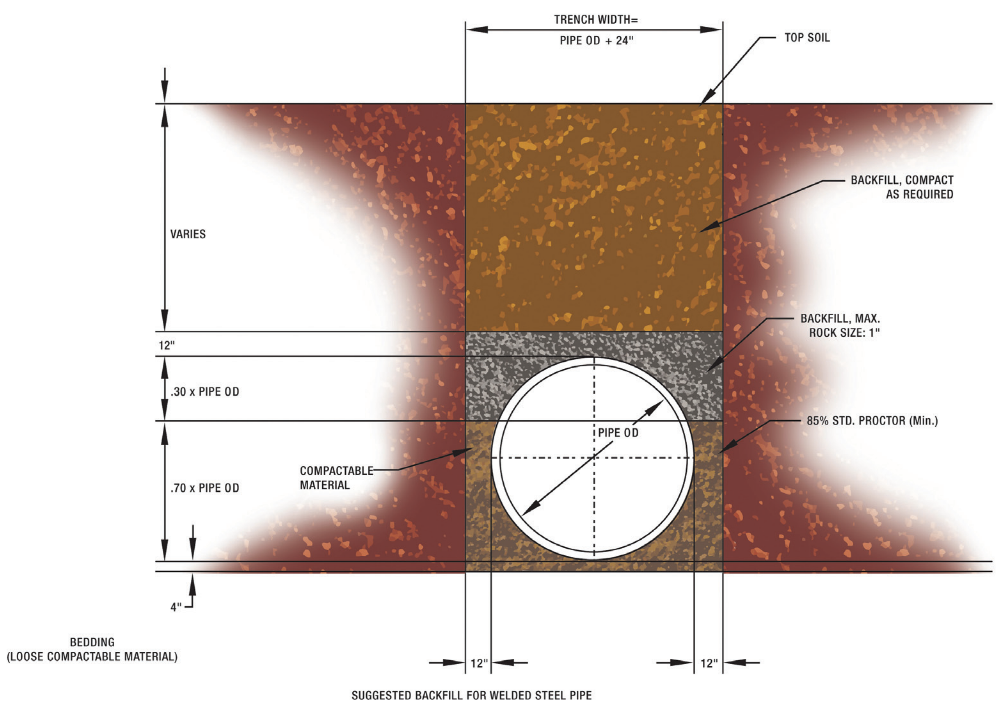
Where: W_L = live load on pipe per unit length, lb/in.

Reference **Table 2.2** for standard HS-20 highway and E-80 railroad loading.

In either of the above cases, when the q_a is not adequate to resist the buckling loads, the soil envelope should first be investigated to increase the allowable E'.

Trench Configuration

An accepted industry standard suggests that the minimum trench width be no less than the outside diameter of the pipe plus 24 in. (D + 24 in.). This recommended trench width provides the minimum, practical space on each side of the pipe to compact the embedment material as required to obtain the necessary degree of relative compaction. For installation in areas with extremely poor native soil (frequently taken as less than 4 blows per foot), the suggested total trench width should be equal to approximately twice the pipes' outside diameter (D x 2). This trench width will have the net effect of reducing the lateral pressure of the embedment material against the poor native soil trench walls. Placement of compacted bedding and backfill material to a height equivalent to 0.7 times the pipe outside diameter (0.7D) should be adequate for structural support of the pipe.



Suggested Backfill for Welded Steel Pipe

Design Example

The following will outline a sample design for a 72-in. pipeline based on the criteria listed:

Given:	Pipe Outside Diameter (D)	74.250 in.
	Working Pressure (P_w)	160 psi
	Total Transient Pressure (P_t)	220 psi
	Field Test Pressure (P_{test})	200 psi
	Vacuum Pressure	8 psi
	Height of Cover (H)	4-18 ft
	Height of Water Above Pipe (h_w)	4 ft
	Cylinder Material	ASTM A139, Grade C (42 ksi minimum yield)
	Allowable Stress at P_w	50% of minimum yield
	Allowable Stress at P_t or P_{test}	75% of minimum yield
	Embedment Material Compaction	Coarse-grained with fines AASHTO 90% relative compaction
	Pipe Lining	0.5-in. cement mortar – in accordance with AWWA C205
	Pipe Coating	80 mil tape - in accordance with AWWA C214

1. DESIGN FOR INTERNAL PRESSURE

The pipe must be designed for the pressure conditions listed above: operating or working pressure; and max[total transient pressure , field test pressure]. The larger of the two calculated values for the wall thickness will govern in the design. Refer to *Internal Pressure*, page 4.

t = PD/2S

a. Thickness required at operating or working pressure:

$$t_{Pw} = \frac{160(74.250)}{2(.5)(42{,}000)} = 0.283 \text{ in.}$$

b. Evaluating max [220 , 200] yields the total transient pressure as the larger of the two. Thickness required at total transient pressure:

$$t_{Pt} = \frac{220(74.250)}{2(.75)(42{,}000)} = 0.259 \text{ in.}$$

Based on the calculated values for internal pressure, condition **a**, "Thickness required for operating or working pressure," governs the design. Therefore, the nominal wall thickness of the pipe should be 0.283 in. to resist internal pressure. The next step in the design process is to ensure that this calculated thickness will be adequate with respect to handling.

2. CHECK FOR HANDLING

In this example the pipe is lined per AWWA C205 with cement mortar and coated per AWWA C214 with an 80-mil polyethylene tape. Refer to *Handling*, page 4.

Cement mortar lined pipe: $\mathbf{D_n/t = 240}$

$$72/t = 240$$

Required thickness for handling $t = 0.300$ in.

As the thickness required for handling is greater than the thickness required for internal pressure, the minimum thickness required for handling will govern. Therefore the nominal wall thickness for the pipe should be 0.300 in. Next, this thickness (0.300 in.) should be used to check the adequacy of the pipe/soil system stiffness for resistance to external loads.

Note that pipe with a 0.300 in. thickness will be able to withstand an operating pressure of 170 psi and a transient/test pressure of 255 psi.

3. CHECK FOR EXTERNAL LOAD

The value for the modulus of soil reaction, E′, will vary with depth of cover as noted in **Table 2.3**; therefore, the deflection should be verified for the maximum cover for each E′ value. For simplicity, the following evaluation is based on the minimum cover of 4 ft and the maximum cover of 18 ft. Refer to *External Loading*, page 5.

a. External Load at 4 ft of cover.

$$\Delta_x = \left(\frac{D_l K W r^3}{EI + 0.061E'r^3}\right)$$

Where: Deflection Lag Factor (D_l) = 1.0

Bedding Constant (K) = 0.10

Earth Load (dead load + live load):

$$W = W_E + W_L$$

$W_E = 4(120)74.250/12 = 2{,}970$ lb/ft of pipe
$W_E = (2{,}970)/12 = 248$ lb/in. of pipe

Per **Table 2.2**, Live Load at 4 ft is 2.8 psi, therefore $W_L = 2.8(D)$

$W_L = 2.8(74.250)$
$W_L = 208$ lb/in. of pipe
$W = W_E + W_L$
$W = (248) + (208)$
$W = 456$ lb/in. of pipe

Mean radius of pipe (r) =
$r = (D - t_c - t_l)/2$
$r = (74.250\text{-}0.300\text{-}0.5)/2 = 36.725$ in.

From **Table 2.3**, E′= 1,000 psi for embedment material that is coarse-grained with fines, compacted to 90% relative compaction, at 4 ft of cover.

Pipe Stiffness (EI)

$$\Sigma EI = E_S I_S + E_l I_l$$
$$= (30\text{x}10^6(0.300)^3/12) + (4\text{x}10^6(0.5)^3/12)$$
$$= 67{,}500 + 41{,}667 = 109{,}167 \text{ in-lb}$$

$$\Delta_x = \left(\frac{D_l K W r^3}{EI + 0.061E'r^3}\right)$$

$$\Delta_x = \frac{1.0(0.10)(456)(36.725)^3}{109{,}167 + 0.061(1000)(36.725)^3} = 0.72 \text{ in.}$$

The allowable deflection for “Cement Mortar Lining x Flexible Coating” = 3% of the pipe diameter.

Δ_x -ALLOWABLE = 0.03(72)
Δ_x -ALLOWABLE = 2.16 in.
$\Delta_x \leq \Delta_x$ -ALLOWABLE = 0.72 in. (1%) $\leq$ 2.16 in. (3%), True, therefore Δ_x is OK.

The pipe design for 4 ft of cover is satisfactory for the defined conditions.

b. External Load at 18 ft of cover.

$$\Delta_x = \left(\frac{D_l K W r^3}{EI + 0.061E'r^3} \right)$$

Where:

Deflection Lag Factor (D_l) = 1.0
Bedding Constant (K) = 0.10
Earth Load (dead load):
$W = W_E + {}^*W_L$
$W = 18(120)74.250/12 =$ 13,365 lb/ft of pipe
$W = (13,365)/12 =$ 1,114 lb/in. of pipe
*Note: Depth of cover is greater than 8 ft, $W_L = 0$

Mean radius of pipe (r) = 36.725 in.
(from above)

From **Table 2.3**, E′= 2,000 psi for embedment material that is coarse-grained with fines, compacted to 90% relative compaction, at 18 ft of cover.

Pipe Stiffness (EI)

$\Sigma EI = E_S I_S + E_l I_l = 109,167$ in-lb (from above)

$$\Delta_x = \left(\frac{D_l K W r^3}{EI + 0.061E'r^3} \right)$$

$$\Delta_x = \frac{1.0(0.10)(1114)(36.725)^3}{109,167 + 0.061(2000)(36.725)^3} = 0.90 \text{ in.}$$

The allowable deflection for "Cement Mortar Lining x Flexible Coating" = 3% of the pipe diameter.

Δ_x -ALLOWABLE = 0.03(72)
Δ_x -ALLOWABLE = 2.16 in.

$\Delta_x \leq \Delta_x$ -ALLOWABLE = 0.90 in. < 2.16 in., True, therefore Δ_x is OK.

The pipe design for 18 ft of cover is satisfactory for the defined conditions.

4. CHECK FOR BUCKLING

In this example, confirmation of resistance to buckling will include an analysis of the external loads relative to the pipe stiffness. The sum of external loads must be less than or equal to the pipe's allowable buckling pressure, qa, which for this example is determined as follows:

a. Buckling design for 4 ft of cover.

$$q_a = (1/FS)(32R_w B'E'(EI/D^3))^{1/2}$$

Where:

q_a = allowable buckling pressure, psi

$FS = 2.0$

$R_w = 1\text{-}0.33(h_w/H)$

$= 1\text{-}0.33(4)/(4)$

$= 0.67$

$$B' = \frac{1}{1 + 4e^{(-.065H)}}$$

$$B' = \frac{1}{1 + 4e^{(-.065)(4)}}$$

$B' = 0.2448$

$E' = 1000$ psi

Pipe Stiffness (EI)

$\Sigma EI = E_s I_s + E_l I_l = 109{,}167$ in-lb (from above)

$D = 74.250$ in.

$$q_a = (1/FS)\left(32R_w B'E'(EI/D^3)\right)^{1/2}$$

$$= \frac{1}{2}\left(32\,(0.67)(0.2448)(1000)\,\frac{109{,}167}{409{,}345}\right)^{1/2}$$

$= 18.7$ psi

External Loads are now calculated and must not exceed qa.

$$q_a > \gamma_w h_w + \frac{R_w W_c}{D} + Pv$$

Where:

$q_a = 18.7$ psi

$\gamma_w = 0.0361$ lbs/in.^{3}

h_w = 48 in.
R_w = 0.67
W_c = 248 lbs/in.
D = 74.250 in.
P_v = 8.0 psi

$$18.7 \geq (0.0361)(48) + \frac{(0.67)(248)}{74.250} + 8.0$$

$$18.7 \geq 12.0$$ External Loading OK for 4 ft of cover.

b. Live load consideration for 4 ft of cover.

$$q_a \geq \gamma_w h_w + \frac{R_w W_c}{D} + \frac{W_L}{D}$$

q_a = 18.7 psi
γ_w = 0.0361 lbs/in.^{3}
h_w = 48 in.
R_w = 0.67
W_c = 248 lbs/in.
W_L = 208 lbs/in.
D = 74.250 in.
P_v = 8.0 psi

$$18.7 \geq (0.0361)(48) + \frac{(0.67)(248)}{74.250} + \frac{208}{74.250}$$

$18.7 \geq 6.8$ Live Loading OK for 4 ft of cover.

c. Buckling design for 18 ft of cover.

$$q_a = (1/FS)(32R_w B'E'(EI/D^3))^{1/2}$$

Where: q_a = allowable buckling pressure, psi
FS = 2.0
Rw = 1-0.33(h_w/H)
= 1-0.33(4)/(18)
= 0.93

$$B' = \frac{1}{1 + 4e^{(-.065H)}}$$

$$B' = \frac{1}{1 + 4e^{(-.065)(18)}}$$

B' = 0.4461

$E' \quad = 2000$ psi

Pipe Stiffness (EI)

$\Sigma EI \quad = E_s I_s + E_l I_l = 109{,}167$ in-lb (from above)

$D \quad = 74.250$ in.

$$q_a = (1/FS)\left(32R_w B'E'(EI/D^3)\right)^{1/2}$$

$$= \frac{1}{2}\left(32\,(0.93)(0.4461)(2000)\,\frac{109{,}167}{409{,}345}\right)^{1/2}$$

$$q_a = 42.1 \text{ psi}$$

External Loads are now calculated and must not exceed qa.

$$q_a > \gamma_w h_w + \frac{R_w W_c}{D} + P_v$$

$q_a \quad = 42.1$ psi

$\gamma_w \quad = 0.0361$ lbs/in.^{3}

$h_w \quad = 48$ in.

$R_w \quad = 0.93$

$W_c \quad = 1{,}114$ lbs/in.

$D \quad = 74.250$ in.

$P_v \quad = 8.0$ psi

$$42.1 \geq (0.0361)(48) + \frac{(0.93)(1{,}114)}{74.250} + 8.0$$

$42.1 \geq 23.7$ psi External Loading OK for 18 ft of cover.

Normal live loads at depth exceeding 8 ft are insignificant and therefore no calculation will be required at 18 ft of cover.

5. Determine factory test pressure:

$$\mathbf{P = 2t(.75S)/D}$$

$$P = \frac{(2)(.300)(.75)(42{,}000)}{74.250} \qquad = 255 \text{ psi}$$

AMERICAN

SPIRALWELD PIPE

THE RIGHT WAY

A Subsidiary of AMERICAN
P.O. Box 2727
Birmingham, AL 35202-2727
Phone: 1-866-442-ASWP (2797)
Email: aswpcustomerservice@acipco.com

WWW.AMERICAN-USA.COM