Ductile Iron Pipe Research Association

Strength and Durability for Life®

DESIGN

Design of Ductile Iron Pipe

Last Revised:
May 2016

With more than six decades of outstanding field experience, Ductile Iron Pipe is widely recognized as the industry standard for modern water and wastewater systems.

One of the most important reasons for the success of Ductile Iron Pipe is that, like Gray Iron pipe before it, it is the subject of the most extensive series of product standards in the pipe industry. Since the 1920s, American National Standards Institute—now the American Water Works Association—Standards Committee A21 has been responsible for this series of standards on Gray and Ductile Iron Pipe. Since Ductile Iron Pipe was first introduced in 1955, the Standards Committee on Ductile Iron Pipe and Fittings has been provided with extensive data on trench loading tests, strength tests, corrosion resistance, tapping strength, flow characteristics, impact resistance, lining and joint integrity, and virtually all aspects of the material that can affect its performance.

From this data and the dedicated work of the members of AWWA Standards Committee A21, the American National Standard for the Thickness Design of Ductile Iron Pipe (ANSI/AWWA C150/A21.50) has evolved. No more thorough and comprehensive standard design procedure exists for any piping material.

Design Basis

The basis of the design standard for Ductile Iron Pipe is the long established fact that Ductile Iron Pipe, subjected to internal pressure and underground loading conditions, behaves as a flexible conduit and rerounds under pressure. Therefore, the pipe is designed separately to withstand external loads and internal pressure. The result is more conservative than designing for the combined loading condition. Thus the separate stress design approach was chosen as the basis of the original ANSI standard in 1965.

Briefly, the design procedure for Ductile Iron Pipe includes:

1. Design for internal pressures (static pressure plus surge pressure allowance).
2. Design for bending stress due to external loads (earth load plus truck loads).
3. Select the larger resulting net wall thickness.
4. Add an 0.08-inch service allowance.
5. Check deflection.
6. Add the standard casting tolerance.

This procedure results in the total calculated design thickness, from which the appropriate pressure class is chosen.

Important Criteria

The Standards Committee carefully chose the following criteria in the 1976 standard for use in calculating required thickness of Ductile Iron Pipe. These criteria remain unchanged in the current edition of the standard.

1. Earth load is based upon the prism load concept, a very conservative assumption for loads normally experienced by a flexible pipe.
2. Truck loads are based upon a single AASHTO H-20 truck with 16,000 pounds wheel load and an impact factor of 1.5 at all depths.
3. External load design includes calculation of both ring bending stress and deflection. Ring bending stress is limited to 48,000 psi, providing a safety factor of at least 2.0 based upon ultimate bending stress.
4. Deflection of the pipe ring is limited to a maximum of 3 percent for cement-mortar lined pipe. Again, this limit provides a safety factor of at least 2.0 against applicable performance limits of the lining. (Unlined

pipe and pipe with flexible linings are capable of withstanding greater deflections.)

5. Five trench types have been defined in the standard (see Figure 1 and Table 1) to give the designer a selection of laying conditions. This ensures a cost-effective trench section design for varying job conditions.
6. Internal pressure design of standard pressure classes is based on the rated working pressure plus a surge allowance of 100 psi. A safety factor of 2.0 is applied to this sum, which is based on the standard's minimum required yield strength in tension of 42,000 psi.

Internal Pressure Design

The net thickness required for internal pressure is calculated using the equation for hoop stress:

$$t = \frac{P_i D}{2S}$$

where:
t = net pipe wall thickness, in.
P_i = design internal pressure, psi
D = outside diameter of pipe, in.
S = minimum yield strength in tension, psi

The design internal pressure (P_i) is equal to the safety factor of 2.0 times the sum of working pressure (P_w) plus a surge allowance (P_s) for water pipe; that is $P_i = 2.0\,(P_w + P_s)$. The standard surge allowance of 100 psi is adequate for most applications; however, if anticipated surge pressures are other than 100 psi, the actual anticipated surge pressure should be used.

External Load Design

The net wall thickness required for external load is based on two design considerations: limitation of ring bending stress and ring deflection. When a trench load of sufficient magnitude is applied, Ductile Iron Pipe will deflect amply to develop passive resistance from the sidefill soil, thereby transmitting part of the trench load to the sidefill soil. Thus, the load-carrying capacity of Ductile Iron Pipe is a function of soil and ring stiffness. In addition, an upward reaction to the vertical trench load exerted on the pipe develops in the trench embedment below the pipe. This reaction is distributed almost uniformly over the width of bedding of the pipe; the greater the width of bedding, the greater the load-carrying capacity of the pipe. Therefore, certain design criteria dependent on the effective width of bedding and on the available passive resistance of the sidefill soil are essential to calculating ring bending stress and ring deflection of Ductile Iron Pipe. These design criteria have been conservatively established from test data for various standard laying conditions discussed later in this article. (See Table 1.) Also, due to its inherent greater ring stiffness, Ductile Iron Pipe is less reliant on soil support than other flexible pipe materials.

Bending Stress Design

Design maximum ring bending stress for Ductile Iron Pipe is 48,000 psi, which provides safety factors under trench loading of at least 1.5 based on ring yield strength and at least 2.0 based on ultimate ring strength. The following equation is used to calculate the trench load required to develop a bending stress of 48,000 psi at the pipe invert:

$$P_v = \frac{f}{3\left(\frac{D}{t}\right)\left(\frac{D}{t}-1\right)\left[K_b - \dfrac{K_x}{\dfrac{8E}{E'\left(\frac{D}{t}-1\right)^3} + 0.732}\right]}$$

where:
P_v = trench load, psi = $P_e + P_t$
P_e = earth load, psi
P_t = truck load, psi
f = design maximum bending stress, 48,000 psi
D = outside diameter, in.
t = net thickness, in.
K_b = bending moment coefficient (Table 1)
K_x = deflection coefficient (Table 1)
E = modulus of elasticity (24×10^6 psi)
E' = modulus of soil reaction, psi (Table 1)

Net Thickness and Service Allowance

A net thickness is computed using both the internal pressure and bending stress equations as described above. The larger of the two net thicknesses is then selected as the net thickness required for internal pressure and bending stress design. A service allowance (0.08-inch for all pipe sizes) is then added to the larger net thickness. This service allowance provides an additional safety factor for unknowns. The resulting thickness is the minimum thickness t_1.

Deflection Check

Maximum allowable ring deflection for cement-mortar lined Ductile Iron Pipe is 3 percent of the outside diameter. Tests have shown that 3 percent deflection will provide a safety factor of at least 2.0 with regard to failure of the cement-mortar lining. Much larger deflections can be sustained without damage to the pipe wall. The following equation is used to calculate the trench load required to develop a ring deflection of 3 percent of the outside diameter.

$$P_v = \frac{\Delta x/D}{12K_x}\left[\frac{8E}{\left(\frac{D}{t_1}-1\right)^3} + 0.732E'\right]$$

where:

t_1 = minimum thickness, in. (t + 0.08)

Δx = design deflection, in. ($\Delta x/D$ = 0.03)

P_v, K_x, E, E', and D are the same as in the equation for bending stress.

The t_1 required for deflection is compared to the t_1 resulting from internal pressure and bending stress design. The largest t_1 is used and is called the minimum manufacturing thickness.

Allowance For Casting Tolerance

Once the minimum manufacturing thickness is determined, an allowance for casting tolerance is added to provide the latitude required by the manufacturing process and to prevent the possibility of significant minus deviation from design thickness. Casting allowance is dependent on the pipe size as shown in the table.

Allowances for Casting Tolerance

Size (inches)	Casting Tolerance (inches)
3-8	0.05
10-12	0.06
14-42	0.07
48	0.08
54-64	0.09

Standard Laying Conditions

As indicated previously, certain factors dependent on the specified type of laying condition are essential to the design of Ductile Iron Pipe for external loads. Two of these factors, the coefficients for bending (K_b) and deflection (K_x), are dependent on the width of bedding at the pipe bottom. The width of bedding is the contact area on the pipe bottom where bedding support is sufficient to develop an equal reaction to the vertical trench load and is commonly referred to as the bedding angle. The other factor is modulus of soil reaction (E'), which is a measure of the passive resistance that can be developed in the sidefill soil. To facilitate design calculations, these factors have been conservatively established from reliable test data for five standard laying conditions (Table 1), thus giving the design engineer a great deal of flexibility in selecting the most economical combinations of wall thickness and bedding and backfill requirements.

Trench Load

The trench load (P_v) used in the design of Ductile Iron Pipe is expressed as vertical pressure in psi, and is the sum of earth load (P_e) and truck load (P_t). Earth load (P_e) is the weight of the unit prism of soil above the pipe to the ground surface. The unit weight of the backfill soil is assumed to be 120 lbs./cu. ft., which is conservative for most soils. In unusual conditions where heavier backfill material is used, the design earth load should be increased accordingly.

The equation used to compute earth load is as follows:

$$P_e = \frac{wH}{144} = \frac{120H}{144} = \frac{H}{1.2}$$

where:
P_e = earth load, psi
w = soil weight, 120 lbs./cu. ft.
H = depth of cover, ft.

Truck load (P_t) is based on a single AASHTO H-20 truck on unpaved road or flexible pavement, having a 16,000 pound wheel load and using a 1.5 impact factor at all depths. The equation used to compute truck load is as follows:

$$P_t = RF \frac{CP}{bD}$$

where:
P_t = truck load, psi
R = reduction factor which takes into account that the part of the pipe directly below the wheels is aided in carrying the truck load by adjacent parts of the pipe that receive little or no direct load from the wheels (Table 2)
F = impact factor, 1.5
C = surface load factor calculated for a single concentrated wheel load centered over an effective pipe length of 3 ft.
P = wheel load, 16,000 lbs.
b = effective pipe length, 36 in.
D = outside diameter of pipe, in.

The surface load factor, C, is a measure of how the wheel load at the surface is transmitted and distributed through the soil to the pipe. The equation used to calculate the surface load factor is as follows:

$$C = 1 - \frac{2}{\pi} \arcsin\left[H\sqrt{\frac{A^2 + H^2 + 1.5^2}{(A^2 + H^2)(1.5^2 + H^2)}}\right] + \frac{2}{\pi}\left(\frac{1.5AH}{\sqrt{A^2 + H^2 + 1.5^2}}\right)\left[\frac{1}{A^2 + H^2} + \frac{1}{1.5^2 + H^2}\right]$$

(Note: angles are in radians.)

where:
H = depth of cover, ft.
A = outside radius of pipe, ft.
Earth loads (P_e), truck loads (P_t), trench loads (P_v) and surface load factors (C) computed using the above equations are listed in ANSI/AWWA C150/A21.50 for depths of cover ranging from 2.5 feet to 32 feet.

Design Tables

Manual use of the equations for bending stress and deflection to determine net thickness is somewhat lengthy and time-consuming. To expedite calculations, design tables giving diameter-thickness ratios for a wide range of trench loads have been developed from these equations for all five standard laying conditions. With these design tables, a designer need only know trench load and desired laying condition to compute net thickness required for bending stress design and deflection design.

Standard Pressure Classes

Ductile Iron Pipe is manufactured in standard pressure classes (150-350) which vary in thickness depending on pipe size. (See Table 3.) Pressure classes are defined as the standard rated water working pressure of the pipe in psi. The thickness shown for each pressure class is thus adequate for the rated water working pressure plus a surge allowance of 100 psi. Once the total calculated thickness has been determined for a particular application, the appropriate standard pressure class thickness should be selected for purposes of specifying and ordering. When the calculated thickness is between two standard thicknesses, the larger of the two should be selected.

Standard Selection Table

Using the design procedure described, a standard selection table (Table 4) was developed that gives maximum depth of cover for each standard pressure class and laying condition. This table was provided so that a designer may simply select, rather than calculate, the appropriate pressure class and laying condition for a given design application. For extraordinary design conditions not shown in the table, such as extremely high internal pressures or extreme depths of cover, it may be advisable to consult DIPRA member companies for recommendations to maximize system design.

Safety Factor

As stated, the safety factor for internal pressure is 2.0 based on minimum yield strength of Ductile Iron in tension. For external loads, two explicit safety factors are specified: at least 1.5 based on ring yield strength and at least 2.0 based on ultimate strength. Also, the design ring deflection check provides a safety factor of at least 2.0 based on test data regarding deflections required to cause failure in cement-mortar lining.

The above explicit safety factors are used to establish a design criteria and should not be confused with the total available safety factor of Ductile Iron Pipe, which has been shown to be much greater than the specified safety factors used in design calculations for the following reasons:

1. The stringent design criteria for Ductile Iron Pipe are not based on the much greater performance limits associated with failure of the pipe wall.
2. Specified safety factors are used to calculate net wall thickness requirements, after which both service allowance and casting allowance are added. (For example, the nominal wall thickness of 30-inch Class 150 Ductile Iron Pipe is approximately 180 percent of the net wall thickness required by design.
3. The physical properties of Ductile Iron Pipe will consistently exceed the minimum values specified for design.
4. Ductile Iron Pipe can sustain stresses considerably higher than yield strength determined by standard test methods without damage to the pipe wall.
5. Design considerations dependent on laying conditions were established on a conservative basis.

In the early 1960s, extensive tests were conducted on Ductile Iron Pipe to determine average values for tensile strength, ring strength, hardness, and elongation. Test pipes ranged in size from 2 inches to 24 inches and represented five different producers. These test results showed the average bursting tensile strength to be 52,320 psi and the average ring yield strength to be 84,880 psi for all pipes tested. These values remain consistent when compared to test data derived from burst tests and ring crush tests that have been conducted since that time. Using these values, an example of total safety factor with regard to internal pressure design can be made:

To determine the total safety factor of 6-inch Pressure Class 350 Ductile Iron Pipe with respect to internal pressure for 350 psi working pressure and a standard surge pressure allowance of 100 psi:

1. Compute the hoop stress developed using the minimum manufacturing thickness:

$$S = \frac{P_i D}{2t_1}$$

a. Let P_i = 350 + 100 = 450 psi since total safety factor is desired.
D = 6.90 in.
b. Nominal thickness of Pressure Class 350 = 0.25 in.
c. Subtract casting tolerance to obtain minimum thickness manufactured (t_1). t_1 = 0.25 - 0.05 = 0.20 in.

$$\therefore S = \frac{(450)\ (6.90)}{(2)\ (0.20)} = 7{,}762.5 \text{ psi}$$

2. Compare computed hoop stress to average bursting tensile strength to determine a representative total safety factor:

$$\frac{52{,}320 \text{ psi average}}{7{,}762.5 \text{ psi computed}} = 6.74$$

The total safety factor for internal pressure design will vary with pipe size, pressure class, and design working pressure, but the above example serves to prove that the total available safety factor of Ductile Iron Pipe is actually much greater than the explicit design safety factor of 2.0.

With regard to external load design, actual external loading tests were conducted on large-diameter Ductile Iron Pipe at Utah State University in the early 1970s to evaluate the C150/A21.50 procedure. From this test data, which was based on rigorous conditions, safety factors were calculated by dividing the loads at cement-mortar lining failure by allowable loads as well as by dividing the loads at pipe failure by the allowable loads. Allowable loads were calculated using the C150/A21.50 design procedure for external loads. This comparison showed that when cement-mortar lining failure was used, the calculated safety factor of the test pipe averaged 2.98; when pipe failure was used, the calculated safety factor averaged 5.46.

Using this data as a basis, it is apparent that the total available safety factor of Ductile Iron Pipe with respect to external loads is far greater than explicit design safety factors of 1.5 and 2.0. Further, the above total available safety factors were determined on the basis of a separate stress design; for a combined stress situation (i.e., external load+internal pressure), the total available safety factor would be even greater because internal pressure would tend to reround the pipe, thereby reducing deflection and ring bending stresses created by external load. It is therefore evident that the total safety factor for Ductile Iron Pipe is much more than adequate, and it is obvious that a thorough analysis of both the pipe material and the design procedure is necessary to properly determine actual comparative safety factors.

Linings

Unless otherwise specified, all Ductile Iron Pipe installed today is normally furnished with a Portland cement-mortar lining that conforms to ANSI/AWWA C104/A21.4. Special linings are also available for applications where standard cement-mortar linings are not applicable.

Polyethylene Encasement

Ductile Iron Pipe, which is manufactured with a standard shop coating, needs no external protection in the majority of installations. There are, however, highly aggressive soil conditions and/or stray current conditions where the use of external protection for the pipe is warranted. In these instances, encasing the pipe with polyethylene in accordance with the ANSI/AWWA C105/A21.5 Standard is the generally recommended method of protection.

In 2013, DIPRA introduced V-Bio®, an enhanced version of polyethylene encasement. Taking advantage of co-extrusion technologies for making polyethylene films, V-Bio® is infused with a corrosion inhibitor and an anti-microbial to actively prevent the formation of a corrosion cell under the encasement. V-Bio® adds a new dimension to the already successful polyethylene encasement that has protected thousands of miles of Gray and Ductile Iron Pipe in aggressive soil.

Summary

In the current edition of ANSI/AWWA C150/A21.50, design criteria are:

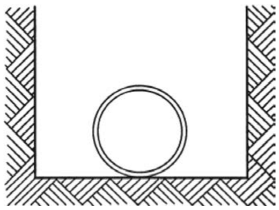
- yield strength in tension, 42,000 psi
- ring bending stress, 48,000 psi
- ring deflection, 3 percent
- AASHTO H-20 truck loading at all depths with 1.5 impact factor
- prism earth load for all pipe sizes, and
- five types of laying conditions

Minimum explicit safety factors are set, but actual total field service safety factors far exceed these values. Unparalleled field service history, improvements in manufacturing and quality control, and research results, including load tests and its inherent corrosion resistance, have led to the establishment of the procedures outlined in this article for the design of Ductile Iron Pipe.

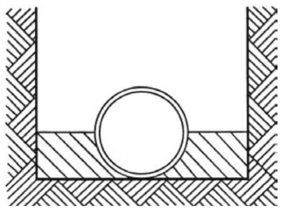
Note: DIPRA has developed a computer program to perform these and other design calculations. The program runs online on our website. (www.dipra.org).

FIGURE 1

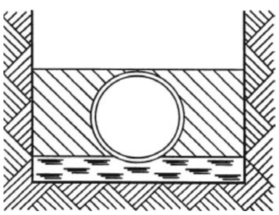
Standard Laying Conditions for Ductile Iron Pipe



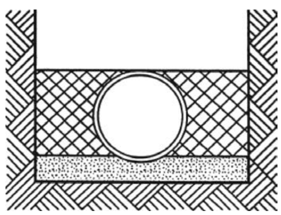
Type 1*
Flat-bottom trench.†
Loose backfill.



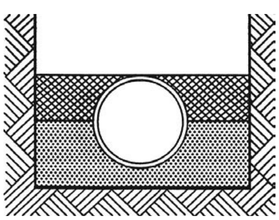
Type 2
Flat-bottom trench.†
Backfill lightly consolidated to centerline of pipe.



Type 3
Pipe bedded in 4-inch minimum loose soil.‡ Backfill lightly consolidated to top of pipe.



Type 4
Pipe bedded in sand, gravel, or crushed stone to depth of 1/8 pipe diameter, 4-inch minimum. Backfill compacted to top of pipe. (Approximately 80% Standard Proctor, AASHTO T-99.)§
(See Table 1 for notes.)



Type 5
Pipe bedded to its centerline in compacted granular material,** 4-inch minimum under pipe. Compacted granular or select‡ material to top of pipe. (Approximately 90% Standard Proctor, AASHTO T-99.)§

TABLE 1

Laying Condition†	Description	E' psi	Bedding Angle Degrees	K_b	K_x
Type 1*	Flat-bottom trench.† Loose backfill.	150	30	0.235	0.108
Type 2	Flat-bottom trench.† Backfill lightly consolidated to centerline of pipe.	300	45	0.210	0.105
Type 3	Pipe bedded in 4-in minimum loose soil.‡ Backfill lightly consolidated to top of pipe.	400	60	0.189	0.103
Type 4	Pipe bedded in sand, gravel, or crushed stone to depth of 1/8 pipe diameter, 4-in. minimum. Backfill compacted to top of pipe. (Approx. 80 percent Standard Proctor, AASHTO T-99.)§	500	90	0.157	0.096
Type 5	Pipe bedded to its center-line in compacted granular material,** 4-in. minimum under pipe. Compacted granular or select‡ material to top of pipe. (Approx. 90 percent Standard Proctor, AASHTO T-99.)§	700	150	0.128	0.085

Note: Consideration of the pipe-zone embedment condition included in this table may be influenced by factors other than pipe strength. For additional information see ANSI/AWWA C600 "Standard for Installation of Ductile Iron Mains and Their Appurtenances."
* For pipe 14 in. and larger, consideration should be given to the use of laying conditions other than Type 1.
**Granular materials are defined per the AASHTO Soil Classification System (ASTM D3282) or the United Soil Classification System (ASTM D2487), with the exception that gravel bedding/backfill adjacent to the pipe is limited to 2" maximum particle size per ANSI/AWWA C600.
† Flat-bottom is defined as "undisturbed earth."
‡ Loose soil or select material is defined as "native soil excavated from the trench, free of rocks, foreign material, and frozen earth."
§ AASHTO T-99, "Moisture Density Relations of Soils Using a 5.5 pound Rammer 12-in. Drop."

TABLE 2
Reduction Factors R for Truck Load Calculations

Size (inches)	Depth of Cover – ft.			
	<4	4-7	7-10	>10
3-12	1.00	1.00	1.00	1.00
14	0.92	1.00	1.00	1.00
16	0.88	0.95	1.00	1.00
18	0.85	0.90	1.00	1.00
20	0.83	0.90	0.95	1.00
24-30	0.81	0.85	0.95	1.00
36-64	0.80	0.85	0.90	1.00

TABLE 3
Standard Pressure Classes and Nominal Thicknesses of Ductile Iron Pipe

Size (inches)	Outside Diameter (inches)	Pressure Class 150	200	250	300	350
		Nominal Thickness (inches)				
3	3.96	–	–	–	–	0.25*
4	4.80	–	–	–	–	0.25*
6	6.90	–	–	–	–	0.25*
8	9.05	–	–	–	–	0.25*
10	11.10	–	–	–	–	0.26
12	13.20	–	–	–	–	0.28
14	15.30	–	–	0.28	0.30	0.31
16	17.40	–	–	0.30	0.32	0.34
18	19.50	–	–	0.31	0.34	0.36
20	21.60	–	–	0.33	0.36	0.38
24	25.80	–	0.33	0.37	0.40	0.43
30	32.00	0.34	0.38	0.42	0.45	0.49
36	38.30	0.38	0.42	0.47	0.51	0.56
42	44.50	0.41	0.47	0.52	0.57	0.63
48	50.80	0.46	0.52	0.58	0.64	0.70
54	57.56	0.51	0.58	0.65	0.72	0.79
60	61.61	0.54	0.61	0.68	0.76	0.83
64	65.67	0.56	0.64	0.72	0.80	0.87

* Calculated thicknesses for these sizes and pressure ratings are less than those shown above. These are the lowest nominal thicknesses currently available in these sizes.

Pressure classes are defined as the rated water working pressure of the pipe in psi. The thicknesses shown are adequate for the rated water working pressure plus a surge allowance of 100 psi. Calculations are based on a minimum yield strength in tension of 42,000 psi and 2.0 safety factor times the sum of working pressure and 100 psi surge allowance.

Thickness can be calculated for rated water working pressure and surges other than the above by use of the design procedure outlined in this article and detailed in ANSI/AWWA C150/A21.50.

Ductile Iron Pipe can be utilized for water working pressure greater than 350 psi and is available in thicknesses greater than Pressure Class 350. Contact DIPRA member companies on specific requirements.

TABLE 4
Rated Working Pressure and Maximum Depth of Cover

Size (inches)	Pressure† Class psi	Nominal Thickness (inches)	Laying Condition Type 1 Trench	Type 2 Trench	Type 3 Trench	Type 4 Trench	Type 5 Trench
			Maximum Depth of Cover—ft.‡				
3	350	0.25	78	88	99	100§	100§
4	350	0.25	53	61	69	85	100§
6	350	0.25	26	31	37	47	65
8	350	0.25	16	20	25	34	50
10	350	0.26	11	15	19	28	45
12	350	0.28	10	15	19	28	44
14	250	0.28	††	11	15	23	36
	300	0.30	††	13	17	26	42
	350	0.31	††	14	19	27	44
16	250	0.30	††	11	15	24	34
	300	0.32	††	13	17	26	39
	350	0.34	††	15	20	28	44

TABLE 4 - continued
Rated Working Pressure and Maximum Depth of Cover

Size (inches)	Pressure† Class psi	Nominal Thickness (inches)	Laying Condition Type 1 Trench	Type 2 Trench	Type 3 Trench	Type 4 Trench	Type 5 Trench
			Maximum Depth of Cover—ft.‡				
18	250	0.31	††	10*	14	22	31
	300	0.34	††	13	17	26	36
	350	0.36	††	15	19	28	41
20	250	0.33	††	10	14	22	30
	300	0.36	††	13	17	26	35
	350	0.38	††	15	19	28	38
24	200	0.33	††	8*	12	17	25
	250	0.37	††	11	15	20	29
	300	0.40	††	13	17	24	32
	350	0.43	††	15	19	28	37
30	150	0.34	††	—	9	14	22
	200	0.38	††	8*	12	16	24
	250	0.42	††	11	15	19	27
	300	0.45	††	12	16	21	29
	350	0.49	††	15	19	25	33
36	150	0.38	††	—	9	14	21
	200	0.42	††	8*	12	15	23
	250	0.47	††	10	14	18	25
	300	0.51	††	12	16	20	28
	350	0.56	††	15	19	24	32
42	150	0.41	††	—	9	13	20
	200	0.47	††	8	12	15	22
	250	0.52	††	10	14	17	25
	300	0.57	††	12	16	20	27
	350	0.63	††	15	19	23	32
48	150	0.46	††	—	9	13	20
	200	0.52	††	8	11	15	22
	250	0.58	††	10	13	17	24
	300	0.64	††	12	15	19	27
	350	0.70	††	15	18	22	30
54	150	0.51	††	—	9	13	20
	200	0.58	††	8	11	14	22
	250	0.65	††	10	13	16	24
	300	0.72	††	13	15	19	27
	350	0.79	††	15	18	22	30
60	150	0.54	††	5*	9	13	20
	200	0.61	††	8	11	14	22
	250	0.68	††	10	13	16	24
	300	0.76	††	13	15	19	26
	350	0.83	††	15	18	22	30
64	150	0.56	††	5*	9	13	20
	200	0.64	††	8	11	14	21
	250	0.72	††	10	13	16	24
	300	0.80	††	12	15	19	26
	350	0.87	††	15	17	21	29

Note: This table is based on a minimum depth of cover of 2.5 feet. For shallower depths of cover please consult the DIPRA brochure *Truck Loads on Pipe Buried at Shallow Depths.*

† Ductile Iron Pipe is adequate for the rated working pressure indicated for each nominal size plus a surge allowance of 100 psi. Calculations are based on a 2.0 safety factor times the sum of working pressure and 100 psi surge allowance. Ductile Iron Pipe for working pressures higher than 350 psi is available.

‡ An allowance for a single H-20 truck with 1.5 impact factor is included for all depths of cover.

§ Calculated maximum depth of cover exceeds 100 ft.

*Minimum allowable depth of cover is 3 ft.

†† For pipe 14 in. and larger, consideration should be given to the use of laying conditions other than Type 1.

For more information contact DIPRA or any of its member companies.

Ductile Iron Pipe Research Association

An association of quality producers dedicated to the highest pipe standards through a program of continuing research and service to water and wastewater professionals.

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Social Media

Get in the flow with Ductile Iron Pipe by connecting with us on Facebook, Twitter, and LinkedIn.

Visit our website, **www.dipra.org/videos,** and click on the YouTube icon for informational videos on Ductile Iron Pipe's ease of use, economic benefits, strength and durability, advantages over PVC, and more.

Member Companies

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Ductile Iron Pipe is SMART certified