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Ductile Iron Pipe
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MATERIAL COMPARISONS

Ductile Iron Pipe vs. BCCP Pipe

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Still manufactured following the ANSI/AWWA C303[1] standard, the former Pretensioned Concrete Cylinder pipe is now commonly referred to as “Bar-Wrapped Concrete Cylinder Pipe” (BCCP). DIPRA, in its continuing effort to provide service to pipeline engineers and utilities, would like to point out just how BCCP stacks up against Ductile Iron Pipe.

As is usually the case when comparing Ductile Iron Pipe with substitute materials, we find that all pipe materials are not equal. Ductile Iron Pipe’s conservative approaches and distinct advantages tip the scales decidedly in its favor.

BCCP is similar to steel pipe from the standpoint of internal pressure design, installation, corrosion control, field adaptability, pumping costs, and operation and maintenance requirements. Ductile Iron Pipe’s many advantages along those lines will be explored in some detail and, when we conclude, we will have demonstrated why so many utilities and consulting engineers agree that Ductile Iron Pipe is the right decision.

Ductile Iron Pipe Internal Pressure Design is More Conservative

The most important and interesting difference between Ductile Iron Pipe and BCCP is their designs for internal pressure. A careful examination of these materials’ approaches to this important aspect of pipeline specification, while complicated by the composite nature of the concrete pipe, brings to light striking deficiencies in the BCCP method.

Pipe wall thickness design in Ductile Iron Pipe is a simple, yet conservative process. Ductile Iron Pipe is a flexible conduit that is centrifugally cast from homogeneous molten Ductile Iron in accordance with the ANSI/AWWA C151/A21.51 standard “Ductile-Iron Pipe, Centrifugally Cast, for Water.”[2] The pipe is designated as a “pressure class” product, which means that the wall thickness is calculated taking into account both working and surge pressures that the pipeline will experience. “Pressure Class 350” Ductile Iron Pipe has a wall thickness that is calculated using a working pressure of 350 psi and an additional surge pressure of 100 psi with a nominal safety factor of 2.0, resulting in a design pressure of 900 psi.

The preceding description of the pressure class designation exemplifies the process for internal pressure design in the ANSI/AWWA C150/A21.50 standard “Thickness Design of Ductile-Iron Pipe.”[3] In calculating the wall thickness required for internal pressure design, the Barlow Hoop Stress equation is used with the total working and surge pressures being applied against the minimum standard yield strength of Ductile Iron.

$$t = \frac{2.0(P_W + P_S)(D)}{2S}$$

where:
t = pipe wall thickness, in.
P_w = working pressure, psi
P_s = surge pressure, psi
D = outside diameter, in.
S = stress in pipe wall, limited to the minimum tensile yield strength of Ductile Iron, psi (42,000 psi)

Examining the equation, we note that the nominal safety factor of 2.0 doubles the total pipeline pressure. Looking at it another way, this factor of safety limits the wall stress that develops from an internal pressure load to no more than 50 percent of the yield strength of Ductile Iron.

The inherent safety factor is increased in the design process by the addition of a "service allowance" to the wall thickness that results from the internal pressure calculation. The service allowance is a nominal 0.08-inch increase in wall thickness for all diameters and all classes of pipe. Completing the design, an allowance for casting tolerances is added. The size of the allowance is a function of the diameter of the pipe, as follows:

Allowance as a Function of Pipe Size

Nominal Pipe Size, inches	Casting Allowance, inches
3–8	0.05
10–12	0.06
14–42	0.07
48	0.08
54–64	0.09

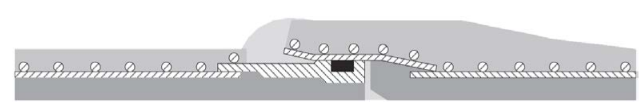
The allowance for the casting tolerance ensures that the wall thickness of the manufactured pipe is greater than the thickness required to sustain the design load. Thus, the casting process cannot compromise the factor of safety used in the design procedure. Further, due to the addition of the service allowance, the inherent safety factor will never be as low as the nominal safety factor of 2.0, even when maximum working plus surge pressures are considered.

Bar-Wrapped Concrete Cylinder Pipe

BCCP is a composite product that is manufactured under the ANSI/AWWA C303 standard "Concrete Pressure Pipe, Bar-Wrapped, Steel-Cylinder Type." It is classified by the concrete pipe industry as a "semi-rigid" pipe in that it does require ring deflection design for external load, but the limits of allowable deflection are very low to prevent cracking of the rigid protective cement-mortar coating. As with Ductile Iron Pipe, separate stress analysis is employed wherein internal pressure and external loads are considered separately. The structural components are a cement-mortar-lined steel cylinder that is helically wrapped with a moderately tensioned round steel bar or wire and coated with, again, cement mortar (see Figure 1). The tension in the bars is simply enough, at least in theory, to ensure that internal pressure will engage both the cylinder and bar steel simultaneously. The cylinder and bar are used to sustain the internal pressure with the cylinder thickness and diameter and spacing of the bar wraps being variables. Jointing is accomplished through a bell and spigot configuration that is fabricated by welding joint rings to the cylinder. For purposes of external load calculations, all components of the pipe are considered bonded as a single unit and, therefore, a composite moment of inertia is used.

FIGURE 1

BCCP Joint



General design considerations are discussed in ANSI/AWWA C303 and a more explicit procedure may be found in AWWA M9, "Manual of Water Supply Practices for Concrete Pressure Pipe,"[4] which is referenced in the manufacturing standard. As with Ductile Iron Pipe design, the Barlow Hoop Stress equation is used, although in a form that addresses the area of steel required (for both cylinder and bar wraps) per linear foot. Further, instead of using a factor of safety that is applied to the internal pressure, a "design factor" is applied to the allowable stress in the steel. The design procedure for BCCP calls for limiting the allowable stress in the steel to 50 percent (Design Factor=0.5) of the tensile yield strength when designing for working pressure, P_w, but allows the stress to go as high as 75 percent of yield when surge pressures are included. This is not a conservative approach because, unlike Ductile Iron Pipe design, it allows a nominal safety factor as low as 1.33 under surge conditions. For working pressure design, the following equation is used:

$$A_S = \frac{6 P_W D_{YI}}{f_S}$$

where:

A_s = area of steel, cylinder plus bar reinforcement, per linear foot

P_w = working pressure, psi

D_{YI} = cylinder inside diameter, in.

f_s = Allowable stress, 50% of tensile yield strength of steel, psi

For working pressure plus surge design, the following equation is used:

$$A_s = \frac{6(P_w + P_s)D_{yi}}{f_{st}}$$

where:

P_s = surge pressure, psi

f_{st} = Allowable stress for transient pressure, 75% of tensile yield strength of steel, psi

Other Design Considerations

Other design considerations are discussed in ANSI/AWWA C303.[5] There is an upper limit set for the steel in the bar reinforcement to be no more than 60 percent of the total steel area (cylinder and bar). Further, the bar area (in.^{2}) per linear foot must be greater than or equal to 1 percent of the inside diameter of the pipe (in.). The clear space between the bar wraps can be no less than the diameter of the bar used; the maximum center-to-center spacing can be no more than 2 inches; the area of bar reinforcement can be no less than 0.23 in.^{2} per linear foot; and the minimum bar size is established at 7/32 of an inch. The minimum nominal cylinder thickness is a function of the pipe diameter and varies from 16 gauge (0.06 in.) for 10- through 21-inch pipe to 10 gauge (0.135 in.) for 51- through 60-inch pipe.

Equivalent Design

There are several significant differences in the respective ways the Ductile Iron Pipe and BCCP industries approach design for internal pressure. For one, Ductile Iron Pipe design uses the outside diameter of the pipe in the Barlow equation when calculating the required thickness of the pipe wall, while BCCP design uses the inside diameter of the steel cylinder. This simple difference is just one example of a design philosophy that results in a more conservative approach for Ductile Iron Pipe compared to BCCP. Other differences, which warrant more detailed discussion, include how surge pressures and material tolerances are addressed.

Surge Pressures

The most glaring difference between the design approaches of Ductile Iron and BCCP is found in the way surge pressures are treated. As noted previously, Ductile Iron Pipe applies a nominal safety factor of 2.0 to both the working and surge pressures (normally 100 psi), while BCCP applies the same 2.0 safety factor (Design Factor=0.5) only to the working pressure. Surge pressures are allowed to increase the tensile stress in the cylinder and the bar wrap to as high as 75 percent of the yield strength of the steel. If so, the nominal safety factor drops from 2.0 (working pressure only) to 1.33 (working plus surge pressure). But, surge pressures occur often enough to warrant more attention for this rigid cement-mortar-coated pipe than the BCCP industry would like. This is just one of several reasons why BCCP should be designed to the same internal pressure parameters that have been used in Ductile Iron Pipe design for decades.

Material Tolerances

There is also a fundamental difference in the way the two pipe products address the tolerances in the material(s) used in their manufacture. As noted earlier, Ductile Iron Pipe casting tolerances are accounted for by increasing the design wall thickness. Thus, if all or part of the casting tolerance is “missing” at some point along the length of a Ductile Iron Pipe, we are assured that the pipe’s ability to hold the pressures for which it was designed is not compromised.

On the other hand, neither the cylinder nor bar wrap tolerances are specifically addressed relative to the effects on safety factor in BCCP design. Because of the way they are manufactured, the tolerances for steel plates, sheets and bars are not as large as for a cast product. However, they should be addressed in a responsible engineering design. Not only does making the tolerances additive (as Ductile Iron Pipe design does) affect the cylinder gauge and bar size, it also affects bar wrap spacing.

How significant can these tolerances be? Let’s find out. If we can establish a more equal design specification, at least with regard to stress safety factors, and perform a design example using that specification, we can compare the results with those of a specification that doesn’t require equal performance.

A More Equal Design – BCCP Minimum Cylinder Thickness

For BCCP to be designed more nearly on a par with Ductile Iron Pipe, the area of steel required in the pipe must be calculated using the outside diameter of the cylinder and applying a nominal factor of safety of 2.0 to the sum of the working and surge pressures. Further, to ensure that manufacturing variability doesn't negatively impact the performance of the pipe, the mill tolerances on the cylinder and bar must be taken into account. This approach will ensure that the inherent factor of safety in BCCP design never drops below 2.0 and that the stress in the steel under maximum design loads never goes above 50 percent of the tensile yield strength of the steel cylinder and bar reinforcement.

Design Example

In our example, we will work through a "more equal design" for BCCP that follows the philosophy employed by the Ductile Iron Pipe industry. This design approach places BCCP design closer to the more conservative plane of Ductile Iron Pipe from an internal pressure design standpoint. Steel used in BCCP manufacture can be of different tensile strengths. We will focus our design example on steel that has a tensile yield strength of 36,000 psi.

Our exercise involves a 24-inch diameter pipe that is to operate under 200 psi working pressure and a 100 psi surge. Our approach will be to use the outside cylinder diameter, apply a nominal factor of safety of 2.0 to the sum of the working and surge pressures, and to account for manufacturing tolerances in the cylinder plate or sheet and bar steels.

Given: Pipe Size (D) ....24-inch nominal diameter
Steel Yield Strength (f_y) .... 36,000 psi
Safety Factor (S_f) 2.0
Lining Thickness (t_L)...................................... 0.75 inches
Working Pressure (P_w).. 200 psi
Surge Pressure (P_s) .... 100 psi
Cylinder Thickness (t_y)... 0.075 inches, minimum (14 gauge)
0.090 inches (13 gauge)
0.105 inches (12 gauge)
Cylinder Thickness Tolerance[6] (t_{yt}) .... 0.01 inches
Diameter of Bar...0.50 inches
Bar Tolerance[7] (t_{bt}) .... 0.003 inches

Determine the Total Area (As) of Steel Required

Our first calculation tells us how much steel is required to sustain the total internal pressure, working plus surge, at a nominal factor of safety of 2.0. (Design Factor=0.5)

$$A_s = \frac{6(P_w + P_s)D_o}{F_D f_Y}$$

where:
D_o = outside diameter of cylinder, in.
F_D = design factor (0.5)

Since the actual inside diameter of BCCP is equal to the nominal pipe size, we need to account for the lining thickness and cylinder thickness to calculate the outside diameter of the cylinder. This will be an iterative process that will select a cylinder size, calculate the resulting area, and work through to determine if that cylinder will account for at least 40 percent of the total required area of steel. To begin, we'll use a 14-gauge cylinder thickness, which is the minimum cylinder thickness for 24-inch pipe in accordance with ANSI/AWWA C303:

$$D_o = D + 2(t_L + t_y)$$

$$D_o = 24 + 2(0.75 \text{ in.} + 0.075 \text{ in.})$$

$$D_o = 25.65 \text{ in.}$$

Therefore, using the Barlow equation:

$$A_s = \frac{6(200 \text{ psi} + 100 \text{psi})(25.65 \text{ in.})}{0.5(36{,}000 \text{ psi})}$$

$$A_s = 2.565 \text{ in.}^2$$

The next step is to determine the area of the cylinder available per linear foot (Ay) to sustain the internal pressure, while accounting for the mill tolerance of the sheet or plate.

$$A_y = (t_y - t_{yt})12$$

$$A_y = (0.075 \text{ in.} - 0.01 \text{ in.})(12 \text{ in.})$$

$$A_y = 0.78 \text{ in.}^2$$

Now, since the total area of steel in the bar wraps can be no more than 60 percent, we must check to ensure that the ratio of cylinder steel to total steel is at least 40 percent.

$$\frac{A_y}{A_s} \geq 40\%$$

$$\frac{0.78 \text{ in.}^2}{2.565 \text{ in.}^2} = 30.41\%$$

✗ No. Increase cylinder thickness.

Since our condition is not met, we try the next thicker cylinder, 13 gauge. The result shows that 13-gauge steel cylinder will only account for some 37 percent of the total steel. Therefore, the calculations are performed again using 12-gauge steel for the cylinder. Recalculating in the same way as before we obtain the following results:

$$D_o = 25.71 \text{ in.}$$

$$A_s = 2.571 \text{ in.}^2$$

$$\frac{1.14 \text{ in.}^2}{2.571 \text{ in.}^2} = 44.3\%$$

✓ Yes. 12-gauge cylinder OK.

The last set of calculations results in an area of steel in the cylinder that meets the minimum 40 percent of total steel requirement. Knowing the cylinder size, we now can calculate the required area of bar reinforcing, bar size and spacing — again, accounting for manufacturing tolerances in the bar. First, we calculate the area of steel per linear foot to be in the bar wraps (A_b):

$$A_b = A_s - A_y$$

$$A_b = 2.571 \text{ in.}^2 - 1.14 \text{ in.}^2$$

$$A_b = 1.431 \text{ in.}^2$$

The rigid steel area in the bar wraps must be 1.431 in.^{2} Next, since the ANSI/AWWA C303 standard calls for a maximum center-to-center spacing of 2 inches between bar wraps, we will calculate the cross sectional area required for a single reinforcing bar (b_a) with the wraps spaced at 2 inches center-to-center:

$$b_a = \frac{A_b(c-c)}{12 \text{ in.}}$$

where:
(c — c) = center-to-center spacing of bars (in.)

$$b_a = \frac{1.431 \text{ in}^2 (2 \text{ in.})}{12 \text{ in.}}$$

$$b_a\{\text{at } (c-c) = 2\text{in.}\} = 0.2385 \text{ in}^2$$

This tells us that, in order to achieve 1.431 in.^{2} of steel in the bars, a single bar must have a cross sectional area of at least 0.2385 in.^{2} at 2 inches center-to-center spacing between wraps. Now we will select an available bar size and calculate the area that bar will have, remembering, again, to account for manufacturing tolerances. Selecting a 1/2-inch diameter bar and subtracting the tolerance from the diameter (t_{bt} = 0.003 in.), we calculate an area for a single bar cross section of 0.194 in.^{2} Since this is less than the bar area of 0.2385 in.^{2} that is required for a 2-inch spacing, the 1/2-inch bar wraps should be spaced closer. To determine how far apart the 1/2-inch bar wraps need to be to achieve that result:

$$(c\text{-}c) = \frac{b_a(12 \text{ in.})}{A_b}$$

$$(c\text{-}c) = \frac{(0.194 \text{ in.}^2)(12 \text{ in.})}{1.431 \text{ in}^2}$$

Center-to-center Spacing, (c-c) = 1.63 in.

This meets the requirement that the bar wraps be no more than 2 inches apart, center-to-center, called for in the ANSI/AWWA C303 standard.

We now must check to ensure that the minimum clear space between bar wraps is greater than the diameter of the bar used:

$$\text{Clear Space} = (\text{c-c}) - (\text{Bar Diameter})$$

$$\text{Clear Space} = 1.63 \text{ in.} - 0.5 \text{ in}$$

$$\text{Clear Space} = 1.13 \text{ in}$$

Since 1.13 inches is greater than the 1/2-inch diameter of the bar we selected, our design is in accordance with the guidelines offered in AWWA M9 and ANSI/AWWA C303.

The Result

In our example, we would call for a 12-gauge steel sheet with a 1/2-inch diameter steel bar to be wrapped around the cylinder at 1.63 inches on-center between wraps. Remember that the design was predicated on keeping the stress in the steel to 50 percent of its tensile yield strength at the total of the working plus surge pressures, using the outside diameter of the cylinder in our calculations and making sure that manufacturing tolerances did not compromise our design.

The Value of a More Equal Design Specification

What would be the result if we had accomplished the design in our example problem without using a comparable design approach? Using the inside diameter of the cylinder and allowing the steel stress to increase to 75 percent of its tensile yield strength, the total area of steel calculated would be 1.70 in.^{2} We would find, following the steps shown previously, that a 14-gauge cylinder, the thinnest cylinder allowed for 24-inch pipe at a thickness of 0.075 inches, would account for some 53 percent of the calculated total area of steel, and that a 3/8-inch bar spaced at 1.66 inches would complete the design.

However, if we analyze this result by factoring the mill tolerances on the steel cylinder and bars to find what the potential minimum area of total steel could be and back into an actual safety factor based on surge conditions, we find that rather than a nominal safety factor of 2.0, we have an actual safety factor as low as 1.22. Comparing Ductile Iron Pipe's inherent factor of safety to the BCCP factor of safety based on an equal design specification and BCCP without comparable design we see the results in the following table:

Comparison of Inherent Factor of Safety
Ductile Iron Versus BCCP
24-Inch Pipe at 300 psi Total Internal Pressure

	DIP	BCCP, More Equal Design Specification	BCCP, per AWWA M9
Required Thickness	0.18 in	—	—
Manufactured Thickness (less casting tolerance)	0.26 in	—	—
Required Area of Steel	—	2.565 in.^{2}	1.70 in^2
Manufactured Area of Steel	—	2.565 in.^{2}	1.57 in^2
Inherent Factor of Safety	2.82	2.0	1.22

Design Aids — BCCP More Equal Design Specification

In the design example, we calculated the required cylinder gauge for 24-inch pipe at 200 psi working and 100 psi surge pressures. We used what is an equivalent design for Pressure Class 200 Ductile Iron Pipe in the 24-inch size when 40 percent of the steel is in the cylinder. To facilitate a comparable design, we can develop a table that lists the required cylinder gauge for all sizes and pressure classes of pipe. The table below does precisely that for 36,000 psi steel based on 40 percent of the steel being in the cylinder.

BCCP Minimum Cylinder Thickness for More Equal Design to Pressure Class Ductile Iron Pipe
40% of Required Steel in Cylinder 36,000 psi Yield Strength

Diameter (Inches)	Minimum Cylinder Thickness (gauge)				
	PC150	PC200	PC250	PC300	PC350
10	—	—	—	—	15
12	—	—	—	—	13
14	—	—	14	13	13
16	—	—	13	13	12
18	—	—	13	12	11
20	—	—	12	11	11
21	—	—	12	11	10
24	—	12	11	10	9
27	—	11	10	9	8
30	12	11	10	8	7
33	11	10	9	8	3/16
36	11	9	8	7	5
39	10	9	7	6	4
42	10	8	3/16	5	1/4
45	9	7	6	4	1/4
48	9	7	5	3	5/16
51	8	3/16	4	1/4	5/16
54	7	5	3	5/16	5/16
57	7	5	1/4	5/16	5/16
60	3/16	4	5/16	5/16	3/8

Tables may also be developed for bar wraps, but the bar size and spacing combinations can vary to achieve the same amount of steel per linear foot. Unlike the table for BCCP cylinders shown here, this variability requires separate tables for each class of pipe. For example, looking at our design example, we selected a 1/2-inch bar, but we could have used a 7/16-inch diameter bar spaced at 1.25 inches on-center or a 3/8-inch bar at 0.92 inches and still designed to an equal design specification. The table below shows the various bar sizes and spacing that would result from the more equal design specification approach that would compare to **Minimum Pressure Class Ductile Iron Pipe** in each size of pipe shown. The table produced is for 36,000 psi steel, again placing 40 percent of the required steel in the cylinder. The table shows the required spacing of different sizes of bar and diameters of pipe, and it has been developed to compare to minimum pressure class Ductile Iron Pipe in each diameter.

Bar Spacing Table for More Equal Design to Minimum Pressure Class DIP 36,000 psi Steel with a Minimum of 40% of Steel in Cylinder										
Diameter (Inches)	Wire/Bar Diameter									
	7/32	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4
10	0.45	0.59	0.92	1.33	1.81	—	—	—	—	—
12	—	0.57	0.89	1.29	1.76	—	—	—	—	—
14	0.45	0.59	0.92	1.33	1.81	—	—	—	—	—
16	—	0.56	0.87	1.26	1.71	—	—	—	—	—
18	—	—	0.68	0.98	1.34	1.74	—	—	—	—
20	—	—	0.65	0.94	1.28	1.67	—	—	—	—
21	—	—	—	0.87	1.18	1.54	1.95	—	—	—
24	—	—	0.63	0.92	1.25	1.63	—	—	—	—
27	—	—	—	0.84	1.15	1.50	1.90	—	—	—
30	—	—	—	0.87	1.19	1.55	1.96	—	—	—
33	—	—	—	0.83	1.13	1.48	1.87	—	—	—
36	—	—	—	—	0.98	1.28	1.62	2.00	—	—
39	—	—	—	—	0.94	1.23	1.55	1.92	—	—
42	—	—	—	—	—	1.08	1.37	1.70	—	—
45	—	—	—	—	—	1.05	1.33	1.64	1.99	—
48	—	—	—	—	—	—	1.19	1.48	1.79	—
51	—	—	—	—	—	—	1.16	1.43	1.74	—
54	—	—	—	—	—	—	—	1.39	1.68	—
57	—	—	—	—	—	—	—	1.27	1.53	1.83
60	—	—	—	—	—	—	—	—	1.46	1.74

Distribution of Steel — Cylinder and Bar Wraps

Before we conclude our discussion on internal pressure design, it is important to note that we have proceeded following the BCCP standard approach of allowing 40 percent of the steel to be in the cylinder. However, this is another example of a less conservative approach to BCCP design. Should there be a manufacturing defect or corrosion failure of the bar, the cylinder is all that is left to hold pressure. If the cylinder accounts for only 40 percent of the required steel, a failure of the bar would mean that the potential factor of safety in the cylinder would fall below 1.0 under surge conditions. In the Barlow model, the steel in the cylinder would go beyond yield and progress toward a potential failure. Against the advent of such a scenario, it would seem to be prudent to place most of the steel in the cylinder rather than the bar wraps. Indeed, some designers require 60 percent of the steel area be in the cylinder. Such an approach doesn't eliminate the problems that a bar failure presents, but it does keep the cylinder from necessarily failing if the bar does. The design steps are the same as above, with the required percentage of steel being adjusted. Similar tables for cylinder gauge and bar spacing for designs that require 60 percent of the steel to be in the cylinder are shown on the following page.

Pipe Size (Inches)	Minimum Cylinder Thickness (gauge)				
	PC150	PC200	PC250	PC300	PC350
10	—	—	—	—	12
12	—	—	—	—	11
14	—	—	12	11	10
16	—	—	11	10	9
18	—	—	10	9	8
20	—	—	9	8	7
21	—	—	9	8	3/16
24	—	9	8	3/16	5
27	—	8	7	5	3
30	9	7	5	4	1/4
33	8	3/16	4	1/4	5/16
36	7	5	3	5/16	5/16
39	3/16	4	1/4	5/16	3/8
42	6	3	5/16	5/16	3/8
45	5	1/4	5/16	3/8	3/8
48	4	5/16	5/16	3/8	7/16
51	3	5/16	3/8	3/8	7/16
54	1/4	5/16	3/8	7/16	7/16
57	5/16	5/16	3/8	7/16	1/2
60	5/16	3/8	3/8	7/16	1/2

BCCP Minimum Cylinder Thickness For More Equal Design to Pressure Class Ductile Iron Pipe
60% of Required Steel in Cylinder 36,000 psi Yield Strength

Bar Spacing Table for More Equal Design to Minimum Pressure Class DIP
36,000 psi Steel with a Minimum of 60% of Steel in the Cylinder

Diameter (Inches)	Wire/Bar Diameter						
	7/32	1/4	5/16	3/8	7/16	1/2	9/16
10	0.82	1.07	1.68	—	—	—	—
12	0.66	0.87	1.36	1.97	—	—	—
14	0.70	0.91	1.43	—	—	—	—
16	0.64	0.84	1.31	1.90	—	—	—
18	0.55	0.72	1.13	1.63	—	—	—
20	0.51	0.67	1.05	1.52	—	—	—
21	0.45	0.59	0.93	1.34	1.82	—	—
24	0.49	0.64	1.01	1.46	1.99	—	—
27	—	0.57	0.89	1.28	1.75	—	—
30	0.46	0.60	0.94	1.35	1.84	—	—
33	—	0.56	0.87	1.26	1.71	—	—
36	—	0.51	0.81	1.16	1.59	—	—
39	—	—	0.71	1.03	1.40	1.82	—
42	—	—	0.63	0.90	1.23	1.61	—
45	—	—	—	0.86	1.17	1.53	1.94
48	—	—	—	0.82	1.12	1.46	1.85
51	—	—	—	0.79	1.07	1.40	1.77
54	—	—	—	—	1.00	1.30	1.65
57	—	—	0.70	1.01	1.38	1.79	—
60	—	—	—	0.85	1.16	1.50	1.91

BCCP Design Tables for 36,000 psi and 33,000 psi Steel

For ease of reference, the design tables shown previously for 36,000 psi steel may be found in the appendix, along with similar design tables for 33,000 psi strength steel. Tables are presented for both strength steels for 40 percent and 60 percent of the steel in the cylinder.

OTHER DUCTILE IRON PIPE ADVANTAGES: IT IS MORE EFFECTIVE, EASIER AND LESS EXPENSIVE TO CONTROL CORROSION ON DUCTILE IRON PIPE THAN IT IS ON BCCP

BCCP Requires a Passivating Coating

For external corrosion control, BCCP relies primarily on a rigid exterior cement-mortar coating. The hydrated cement mortar provides an alkaline environment with an initial pH of approximately 12.5 that is in contact with the steel bar and cylinder. This alkaline environment generates an oxide film on the steel, a process known as passivation. The passivating film protects the steel from galvanic corrosion and will generally do so as long as the coating is intact and not exposed to environments that are corrosive to the mortar or its underlying steel.

However, should any condition develop that results in cracks or damage to the cement-mortar coating, the pipe is then at risk of corrosion failure. The coating can be damaged by an outside mechanical force (such as adjacent construction or rough handling) or from corrosion.

Corrosive Environments for BCCP

Just as there are certain environments that can be potentially corrosive to Ductile Iron Pipe, there are also environments that exhibit corrosive effects on BCCP, either to the steel or cement-mortar coating,[8] or both. Such environments include:

- Soils containing chlorides
- Soils containing sulfates
- Acidic soils (pH less than 5)
- Areas of stray direct current interference

Chloride ions can migrate through the porous cement mortar and break down the passivating film that has developed on the steel. Sulfates will chemically attack the cement mortar and eventually expose the steel to the soil surrounding the pipe. The resulting differential pH will then drive a galvanic corrosion cell on the exposed steel. A low pH environment can also adversely react with the cement mortar, causing it to break down and, again, expose the steel to galvanic corrosion. Finally, BCCP is subject to stray direct current interference if the pipe is placed within the area of influence of a source, most commonly an underground cathodic protection system.

When the soil has been determined to be corrosive, some designers have specified a bonded barrier coating be applied to the cement-mortar coating. This barrier is intended to shield the pipe from the aggressive condition, protecting both the cement mortar and the steel. In stray current environments, if the source of stray current cannot be removed, cathodic protection of the BCCP would be necessary in addition to the application of the bonded barrier coating.

Corrosion Control for Ductile Iron Pipe

In most environments, iron pipe has an inherent resistance to corrosion, as evidenced by the fact that it comprises the oldest pipelines in the world. For example, an iron pipeline in Versailles, France, served well over 300 years. In North America there are more than 570 utilities that received 100 or more years of service, and at least 18 have attained 150 years or more of service from their Cast Iron pipelines. None of these pipelines were supplemented with external corrosion control, a testament to the fact that not all soils are corrosive to iron pipe.

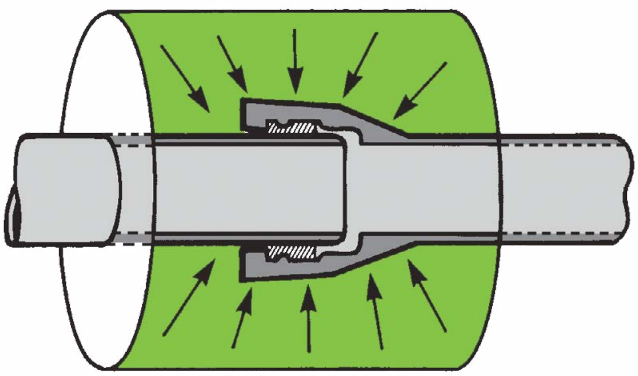
However, there are environments that are potentially corrosive to iron pipe. The corrosivity of a soil to Ductile Iron Pipe may be tested in accordance with procedures outlined in Appendix A of ANSI/AWWA C105/A21.5 standard "Polyethylene Encasement for Ductile-Iron Pipe Systems."[9] If a soil is determined to be potentially corrosive to Ductile Iron Pipe, using polyethylene encasement in accordance with the aforementioned standard will mitigate those effects. Polyethylene encasement is a simple, economical, and effective way to provide corrosion control to Ductile Iron Pipe in all but the most extremely corrosive environments, for example, severe stray current situations.

Ductile Iron Pipe Push-on Joints

The most widely used Ductile Iron Pipe joint for underground service is the push-on joint. This bell and spigot assembly features a synthetic rubber gasket that sits in a recess integrally cast into the bell of each pipe. The push-on joint is extremely effective and easy to assemble. The watertight seal is accomplished during the jointing process by pushing the spigot home into the bell. The outside of the spigot compresses the gasket and forms the seal. It has been tested up to 1,000 psi internal pressure, 430 psi external pressure, and 14 psi internal vacuum pressure without leakage or infiltration (see Figure 2). The push-on joint, along with the mechanical joint, is covered under the ANSI/AWWA C111/A21.11 standard "Rubber-Gasket Joints for Ductile- Iron Pressure Pipe and Fittings."[10]

FIGURE 2

Ductile Iron Push-On Joint Tests

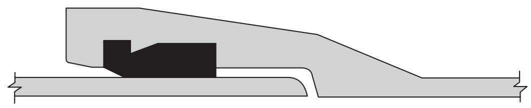


Tested: 1,000 psi Internal Pressure
430 psi External Pressure
14 psi Negative Air Pressure
Results: No Leakage, No Infiltration

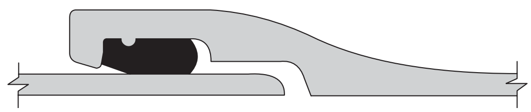
There are two types of push-on joints available for Ductile Iron Pipe: the Fastite® and Tyton® joints. These two joints differ somewhat in shape, but each incorporates a dual-hardness gasket. The gasket shapes are designed so as to seat themselves when subjected to the pipe's internal pressure and they are gaskets that are difficult to dislodge, or roll, during assembly. The Ductile Iron Pipe push-on joint is a flexible joint that affords differential soil movement without building stresses along the length of the pipe as well as providing the capability to help route the pipe in a way that limits the need for fittings. Additionally, the pipe may be cut in the field to a required length, allowing field adjustments not possible with BCCP.

FIGURE 3

Fastite® Joint



Tyton® Joint



Field Cutting BCCP Gasketed Joints is Impractical

A push-on type joint is also used for BCCP. Unlike Ductile Iron Pipe, however, there is no standard for the BCCP joint. Instead of a dual hardness gasket that seats into a bell recess, the BCCP push-on joint includes an O-ring type gasket that is placed into a groove formed on the spigot end of the pipe (see Figure 1). Because the O-ring is placed in a grooved spigot, it is impractical, to the point of being impossible, to make field cuts of BCCP. Further, the BCCP push-on joint provides only a limited deflection capacity during installation. The inability to field-adapt during BCCP installation requires specific laying schedules and line drawings to be provided to the contractor.

Ductile Iron Pipelines Adapt to Field Conditions in Installation

Ductile Iron push-on and mechanical joints, on the other hand, are highly deflectable. That makes it possible, for example, to route a Ductile Iron Pipeline through a gradual curve, thereby avoiding underground structures or to follow a right-of-way while minimizing the need to use fittings. Furthermore, since the gasket is placed into a bell recess, the spigot end of the pipe can be cut in the field to effect quick modifications necessary for avoiding unforeseen obstacles or to make spool pieces on site. Such features give the installer great flexibility and advantages that BCCP cannot offer. In addition to minimizing the need for pipe specials, it also allows for typical, rather than special, bends to be used and makes the type of laying schedules and line drawings required for BCCP installation unnecessary.

The table below shows the minimum deflection capacity of Ductile Iron push-on joints for certain sizes of Ductile Iron Pipe. This table also shows the maximum deflection capacity for BCCP gasketed joints in each of those sizes according to manufacturers' information.

Joint Deflections

Nominal Pipe Size	Ductile Iron Pipe*	BCCP†
12	5	3.10
16	3	2.40
20	3	1.93
24	3	2.18
30	3	1.76
36	3	1.49
42	3	1.29
48	3	1.13
54	3	1.01
60	3	0.92

*Maximum degree of deflection for Ductile Iron Pipe push-on joints as set forth in ANSI/AWWA C600[11]. Greater deflections, up to 5º in many sizes, may be available. Consult with pipe manufacturer.

†Maximum degree of deflection for BCCP as reported in manufacturers' literature.

Ductile Iron Pipe is manufactured in 18- or 20-foot nominal laying lengths. BCCP is furnished in 24-, 32-, 36-, and 40-foot laying lengths, depending upon the size and/or manufacturer. Longer laying lengths, limited deflectability of joints, and the inability to field cut the pipe limits the potential to route the pipe except through fittings or special joints. Also, handling longer lengths of pipe increases the risk of damaging the rigid cement-mortar coatings and linings.

BCCP Joints Require "Pointing" and "Diapering"

After the BCCP joint is assembled the exposed steel must be protected internally and externally from corrosion. This is typically accomplished by coating the inside and outside of the joint with cement mortar.

In smaller diameters, the "pointing" of the inside of the joint is accomplished using a swab mandrel that is pulled through the pipe distributing mortar that had been placed in the bell recess for that purpose. In larger diameters, pointing is accomplished by hand immediately after the joint is assembled.

"Diapering" the outside of the BCCP joint requires the use of a wrapper that is strapped around the circumference of the joint. This "diaper" is then filled with a wet, flowable mix of cement mortar poured into an opening in the diaper at the top of the pipe.

The pointing and diapering of the BCCP joint results in a connection that has virtually no flexibility. Any future consolidation or settling of the ground, or any differential movement of the soil, will stress these joints, opening the possibility for a loosening or cracking of the rigid cement mortar, resulting in exposure of the steel joint rings to potential corrosion. Also, it has been shown that cement mortar placed in the field may not provide the required protection for the steel joint ring area. Ellis[12] states that "pipeline field joints frequently present corrosion difficulties on concrete pipelines and as such represent an inherent weakness in this type of structure."

Ductile Iron Pipe joints need no such diapering or pointing. The end of the spigot abuts the inside of the pipe under the bell resulting in a virtually continuous cement-mortar lining. If corrosive soils are encountered, encasing the pipe in polyethylene protects the outside of the joint. As a result, the flexibility of the Ductile Iron Pipe push-on and mechanical joints is not compromised. This flexibility, coupled with Ductile Iron Pipe's shorter laying lengths, makes Ductile Iron Pipelines less susceptible to damage from differential earth movements over time, even extending into more stringent situations such as those resulting from seismic activity.

Service Taps are Simple on Ductile Iron Pipe

Whether the pipe is encased in polyethylene or installed with only its shop coating, a typical tapping machine can be used to directly install a service tap on Ductile Iron Pipe. Directly tapping all sizes and classes of Ductile Iron Pipe with 3/4-inch corporation stops is possible and, as diameters increase, direct taps of up to 2-inch corporations are readily achieved. Larger connections up to one-half of the main size can be accomplished with tapping saddles and size-on-size connections can be made on many diameters using tapping sleeves. Ductile Iron's standardized outside diameter facilitates the use of on-hand equipment that a utility's inhouse crews can use to increase service to new customers.

Tapping BCCP is not so easy. Since the outside diameter is determined by the internal pressure design, the circumference of the pipe must be measured and the proper saddle ordered before the tap can be performed. The tapping procedure then involves the removal of the cement-mortar coating and the bar wraps at the location where the tap is to be installed. During this process, great care must be exercised to ensure that the pipe is not damaged and that, somehow, the bar wrap steel is still effective in doing its part to hold pressure. Larger taps in BCCP are limited, according to AWWA M9, to a maximum of one size smaller than the pipe size. The complexities associated with tapping BCCP often result in the hiring of tapping contractors or a manufacturer's field services to accomplish this specialized task.

Backfilling is Not as Critical with Ductile Iron Pipe

In flexible conduit design theory, a pipe will support its external load by using its inherent stiffness and, by virtue of its flexibility, mobilizing the side fill soil to help control wall stress and pipe ring deflection. The more effort applied to the backfill in the form of selection and compaction of soils, the more support the backfill will provide. The level of support a backfill condition will provide is exemplified by the soil's Modulus of Soil Reaction, E′, which is measured in psi. The higher the value for E′, the more support is being assumed.

In Ductile Iron Pipe design, the required wall thickness is calculated not just for internal pressure but also for external load. Distinct external load designs for ring bending stress and ring deflection are accomplished in consideration of the various laying conditions that are available. Because of its strength, Ductile Iron Pipe design makes conservative assumptions about the practical aspects of providing that backfill. In other words, even the most supportive backfill condition defined in ANSI/AWWA C150/A21.50 standard for "Thickness Design of Ductile- Iron Pipe" is easily achieved in the field. Further, it is rare that the most supportive laying condition (Type 5) is required. The great majority of installations are able to use a Type 1, 2, or 3 laying condition. If the external load is so great that a Type 5 laying condition is not sufficient, the class of the pipe can be increased.

BCCP is classified as a "semi-rigid" conduit due to the fact that its rigid cement-mortar coating and lining can only sustain a minimal amount of ring deflection. The amount of ring deflection is established by an equation $\Delta x = D^2/4{,}000$, where Δx is the amount of deflection and D is the inside diameter, both in inches.[13] Thus, the maximum allowable deflection will range between 0.025 and 0.9 inches, or between 0.25 and 1.5 percent, for diameters of 10 to 60 inches, compared to cement-mortar-lined Ductile Iron Pipe, which has a maximum deflection limitation in design of 3 percent in all diameters. Further, unlike BCCP design, Ductile Iron Pipe ensures that the wall stresses are not excessive by designing for ring bending stress, again using a factor of safety of 2.0 against the ultimate bending strength of Ductile Iron Pipe.

Unlike Ductile Iron Pipe, where deflection is controlled by conservative wall thickness design, BCCP deflection is controlled mainly by backfill. There is a provision for adding to the thickness of the cement-mortar coating to increase pipe stiffness,[14] but the primary design for BCCP is done for internal pressure. Upon completing that design, the engineer is asked to provide an environment that will help the resulting BCCP support the external load while keeping the deflection at or below its restrictive limit.

It is interesting to consider the BCCP approach to the addition of cement-mortar coating thickness to increase the stiffness of the pipe against external loads. This would be done because the deflection limit for that size of pipe would otherwise be exceeded. The hope is that increasing the thickness of the coating (AWWA M9 allows up to an additional 1.25 inches of thickness) will improve the stiffness and limit deflection to no more than the maximum allowed. However, for a given deflection this also places increased tensile strain on a coating that doesn't handle tension well. Its importance in corrosion control makes it quite a trade-off to risk cracking the cement-mortar coating in order to improve the pipe's ability to sustain an external load.

In accordance with AWWA M9, there are four backfill conditions that the designer can use to help the BCCP support its external load. Labeled S1, S2, S3, and S4, they provide E′ values of 200, 400, 700, and 1,000 psi respectively.[15] Ductile Iron Pipe laying conditions 1 through 5 provide E′ values of 150, 300, 400, 500, and 700 psi, respectively. This simply means that Ductile Iron Pipe generally does not rely as much on side fill soil support as BCCP. Add this to the fact that Ductile Iron Pipe wall thickness design is performed in consideration of external load while BCCP places almost all of its external load design in the soil around its pipe, Ductile Iron Pipe is typically easier to backfill.

Ductile Iron Pipelines are More Energy Efficient than BCCP Pipelines

Another consideration in comparing Ductile Iron and BCCP pipelines is the cost to operate the two respective systems. As noted in the discussion on internal pressure design, the inside diameter of BCCP is equal to the nominal diameter. The inside diameter of cement-mortar-lined Ductile Iron Pipe is typically larger than nominal in generally specified sizes and classes. Thus, for a given flow, the velocity head in Ductile Iron Pipelines will always be lower than in BCCP pipelines. Higher velocities translate into greater head losses; so, higher pumping costs will result for BCCP. When this difference in pumping costs is analyzed over the projected life of the pipeline, a potentially significant cost savings can be realized through Ductile Iron Pipe.

For example, consider a 24-inch transmission pipeline that is 30,000 feet in length and is designed to convey 6,000 gpm in flow rate. The actual inside diameter of cement-mortar-lined, Pressure Class 200 Ductile Iron Pipe is 24.95 inches, while the actual inside diameter for BCCP is 24 inches. This difference represents a flow area for Ductile Iron Pipe that is 8 percent larger than for BCCP. Correspondingly, the respective velocities of flow would be 3.94 fps for Ductile Iron Pipe and 4.26 fps for BCCP. The total head losses over the entire pipeline length would be 51.8 feet for Ductile Iron and 62.6 feet for BCCP. That head loss difference means that it would be 17 percent less expensive to pump through a Ductile Iron Pipeline than through BCCP. Depending on the specific economics of the cost of energy, these annual savings in pumping costs can be brought back to a present worth value that can be used to discount the initial cost to install Ductile Iron Pipe. This figure represents the amount of money that would need to be invested today to offset the increase in pumping costs in BCCP for the design life of the pipeline.[16]

Equivalent Head Loss Pipelines

Another way to compare relative hydraulic characteristics between two pipeline materials is to analyze ways to make the two pipelines equal from a head loss perspective. To do so requires decreasing the head loss in the BCCP pipeline to match the lower values with Ductile Iron; or, increasing the head loss in the Ductile Iron Pipeline to match the higher value for BCCP.

To decrease the head loss in a BCCP pipeline that is 30,000 feet in length so that it equals that of a 24-inch PC 200 Ductile Iron Pipeline, we must provide a BCCP pipeline made of a combination of 24- and 27-inch pipe. For our example, the 30,000 feet of 24-inch PC 200 Ductile Iron Pipeline would be bid against a BCCP pipeline made of approximately 18,100 feet of 24-inch and 11,900 feet of 27-inch pipe. Note that nearly 40 percent of the BCCP main requires up-sizing in order to lower the head losses to equal those of Ductile Iron Pipe. However, this is what is required to achieve equal energy costs of operation for the two competing pipelines. The increase in capital costs for the up-sized substitute BCCP results in a leveling of operations costs associated with pumping water through each pipeline.

Alternatively, if operations costs are less of an issue than up-front costs, the Ductile Iron Pipeline can be bid as a combination of 20- and 24-inch sizes. For our example, the equivalent head loss bid would call for 30,000 feet of 24-inch BCCP versus 25,700 feet of 24- and 4,300 feet of 20-inch Ductile Iron Pipe.

Conclusion

Many advantages exist for the owner, design engineer and contractor when Ductile Iron Pipe is specified. A conservative, straightforward design procedure that takes advantage of Ductile Iron's tremendous strength gives an impressive factor of safety on a pipeline that is easy to construct. Field changes and adaptations further simplify the construction process while operational savings due to lower head losses and reliability of service provide the owner with a winning situation. Supplemental corrosion control, if needed, is effective and economically provided by polyethylene encasement, a simple passive system that requires no monitoring or maintenance.

Further, the owner has the satisfaction of knowing that any normal changes in operating conditions will not likely compromise Ductile Iron Pipe's ability to perform. When pipes compete, they should do so on an equal basis and we feel that the standards should be raised, rather than lowered, to effect greater equality of performance. In order to compare with Ductile Iron Pipe, the competition must improve. But even then, we still find that all pipe materials are not equal. When comparing Ductile Iron Pipe to bar-wrapped concrete cylinder pipe it is obvious that Ductile Iron Pipe is the right decision.

References

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5. ANSI/AWWA C303, Section 4.5.2.2.
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13. AWWA M9, p. 86.
14. AWWA M9, p. 86.
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BCCP Minimum Cylinder Thickness for More Equal Design to Pressure Class Ductile Iron Pipe
40% of Required Steel in Cylinder 36,000 psi Yield Strength

Diameter (Inches)	Minimum Cylinder Thickness (gauge)				
	PC150	PC200	PC250	PC300	PC350
10	—	—	—	—	15
12	—	—	—	—	13
14	—	—	14	13	13
16	—	—	13	13	12
18	—	—	13	12	11
20	—	—	12	11	11
21	—	—	12	11	10
24	—	12	11	10	9
27	—	11	10	9	8
30	12	11	10	8	7
33	11	10	9	8	3/16
36	11	9	8	7	5
39	10	9	7	6	4
42	10	8	3/16	5	1/4
45	9	7	6	4	1/4
48	9	7	5	3	5/16
51	8	3/16	4	1/4	5/16
54	7	5	3	5/16	5/16
57	7	5	1/4	5/16	5/16
60	3/16	4	5/16	5/16	3/8

Bar Spacing Table for More Equal Design to Minimum Pressure Class DIP
36,000 psi Steel with a Minimum of 40% of Steel in Cylinder

Diameter (Inches)	Wire/Bar Diameter									
	7/32	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4
10	0.45	0.59	0.92	1.33	1.81	—	—	—	—	—
12	—	0.57	0.89	1.29	1.76	—	—	—	—	—
14	0.45	0.59	0.92	1.33	1.81	—	—	—	—	—
16	—	0.56	0.87	1.26	1.71	—	—	—	—	—
18	—	—	0.68	0.98	1.34	1.74	—	—	—	—
20	—	—	0.65	0.94	1.28	1.67	—	—	—	—
21	—	—	—	0.87	1.18	1.54	1.95	—	—	—
24	—	—	0.63	0.92	1.25	1.63	—	—	—	—
27	—	—	—	0.84	1.15	1.50	1.90	—	—	—
30	—	—	—	0.87	1.19	1.55	1.96	—	—	—
33	—	—	—	0.83	1.13	1.48	1.87	—	—	—
36	—	—	—	—	0.98	1.28	1.62	2.00	—	—
39	—	—	—	—	0.94	1.23	1.55	1.92	—	—
42	—	—	—	—	—	1.08	1.37	1.70	—	—
45	—	—	—	—	—	1.05	1.33	1.64	1.99	—
48	—	—	—	—	—	—	1.19	1.48	1.79	—
51	—	—	—	—	—	—	1.16	1.43	1.74	—
54	—	—	—	—	—	—	—	1.39	1.68	—
57	—	—	—	—	—	—	—	1.27	1.53	1.83
60	—	—	—	—	—	—	—	—	1.46	1.74

Pipe Size (Inches)	Minimum Cylinder Thickness (gauge)				
	PC150	PC200	PC250	PC300	PC350
10	—	—	—	—	12
12	—	—	—	—	11
14	—	—	12	11	10
16	—	—	11	10	9
18	—	—	10	9	8
20	—	—	9	8	7
21	—	—	9	8	3/16
24	—	9	8	3/16	5
27	—	8	7	5	3
30	9	7	5	4	1/4
33	8		4	1/4	5/16
36	7	5	3	5/16	5/16
39	3/16	4	1/4	5/16	3/8
42	6	3	5/16	5/16	3/8
45	5	1/4	5/16	3/8	3/8
48	4	5/16	5/16	3/8	7/16
51	3	5/16	3/8	3/8	7/16
54	1/4	5/16	3/8	7/16	7/16
57	5/16	5/16	3/8	7/16	1/2
60	5/16	3/8	3/8	7/16	1/2

BCCP Minimum Cylinder Thickness For More Equal Design to Pressure Class Ductile Iron Pipe
60% of Required Steel in Cylinder 36,000 psi Yield Strength

Bar Spacing Table for More Equal Design to Minimum Pressure Class DIP
36,000 psi Steel with a Minimum of 60% of Steel in the Cylinder

Diameter (Inches)	Wire/Bar Diameter						
	7/32	1/4	5/16	3/8	7/16	1/2	9/16
10	0.82	1.07	1.68	—	—	—	—
12	0.66	0.87	1.36	1.97	—	—	—
14	0.70	0.91	1.43	—	—	—	—
16	0.64	0.84	1.31	1.90	—	—	—
18	0.55	0.72	1.13	1.63	—	—	—
20	0.51	0.67	1.05	1.52	—	—	—
21	0.45	0.59	0.93	1.34	1.82	—	—
24	0.49	0.64	1.01	1.46	1.99	—	—
27	—	0.57	0.89	1.28	1.75	—	—
30	0.46	0.60	0.94	1.35	1.84	—	—
33	—	0.56	0.87	1.26	1.71	—	—
36	—	0.51	0.81	1.16	1.59	—	—
39	—	—	0.71	1.03	1.40	1.82	—
42	—	—	0.63	0.90	1.23	1.61	—
45	—	—	—	0.86	1.17	1.53	1.94
48	—	—	—	0.82	1.12	1.46	1.85
51	—	—	—	0.79	1.07	1.40	1.77
54	—	—	—	—	1.00	1.30	1.65
57	—	—	0.70	1.01	1.38	1.79	—
60	—	—	—	0.85	1.16	1.50	1.91

BCCP Minimum Cylinder Thickness for More Equal Design to Pressure Class Ductile Iron Pipe 40% of Required Steel in Cylinder 33,000 psi Yield Strength					
Diameter (Inches)	Minimum Cylinder Thickness (gauge)				
	PC150	PC200	PC250	PC300	PC350
10	—	—	—	—	14
12	—	—	—	—	13
14	—	—	14	13	12
16	—	—	13	12	12
18	—	—	12	11	11
20	—	—	12	11	10
21	—	—	11	10	10
24	—	12	11	10	8
27	—	11	10	9	7
30	11	10	9	8	3/16
33	11	9	8	7	5
36	10	9	7	6	4
39	10	8	3/16	5	3
42	9	7	5	4	1/4
45	8	3/16	5	3	5/16
48	8	6	4	5/16	5/16
51	7	5	3	5/16	5/16
54	3/16	4	1/4	5/16	3/8
57	6	3	5/16	5/16	3/8
60	5	3	5/16	5/16	3/8

Bar Spacing Table for More Equal Design to Minimum Pressure Class DIP 33,000 psi Steel with a Minimum of 40% of Steel in the Cylinder										
Diameter (Inches)	Wire/Bar Diameter									
	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16
10	0.55	0.87	1.26	1.71	—	—	—	—	—	—
12	—	0.76	1.10	1.49	1.95	—	—	—	—	—
14	0.50	0.79	1.14	1.56	—	—	—	—	—	—
16	—	0.74	1.07	1.46	1.90	—	—	—	—	—
18	—	0.66	0.96	1.31	1.70	—	—	—	—	—
20	—	—	0.81	1.10	1.43	1.82	—	—	—	—
21	—	—	0.83	1.14	1.48	1.87	—	—	—	—
24	—	—	0.79	1.07	1.40	1.77	—	—	—	—
27	—	—	—	0.98	1.28	1.63	—	—	—	—
30	—	—	0.84	1.14	1.49	1.88	—	—	—	—
33	—	—	—	0.97	1.27	1.61	1.98	—	—	—
36	—	—	—	0.92	1.20	1.53	1.89	—	—	—
39	—	—	—	—	1.06	1.34	1.65	—	—	—
42	—	—	—	—	1.01	1.28	1.58	1.92	—	—
45	—	—	—	—	—	1.23	1.52	1.84	—	—
48	—	—	—	—	—	—	1.37	1.65	1.97	—
51	—	—	—	—	—	—	1.31	1.59	1.89	—
54	—	—	—	—	—	—	—	1.50	1.78	—
57	—	—	—	—	—	—	—	1.40	1.67	1.96
60	—	—	—	—	—	—	—	—	1.62	1.91

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

Ductile Iron Pipe Research Association

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