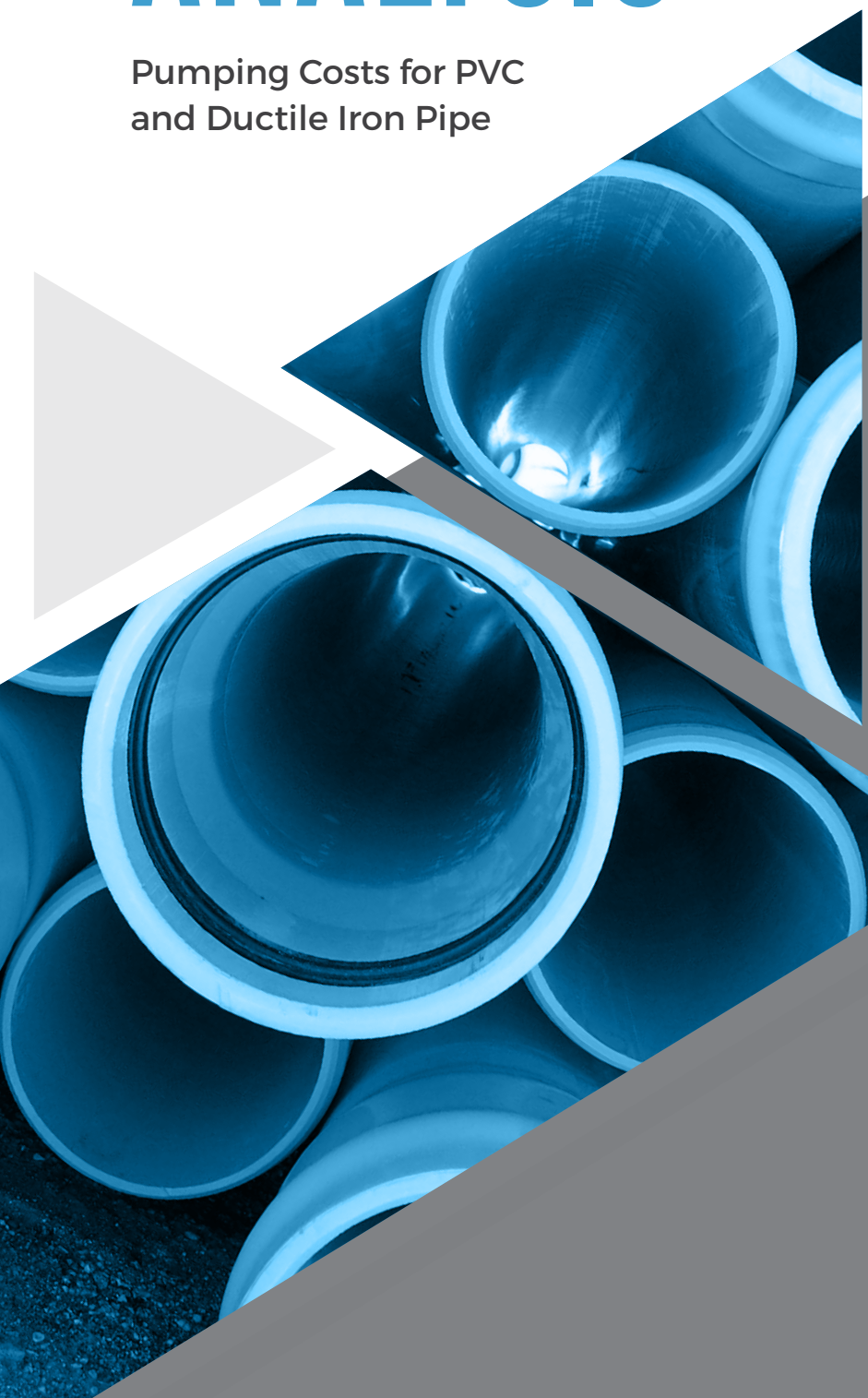
HYDRAULIC ANALYSIS:

Pumping Costs for PVC and Ductile Iron Pipe



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Summary

This paper addresses the inaccurate hydraulic claims made by the Ductile Iron Pipe Research Association (DIPRA) and shows that when industry-accepted data are used, PVC pipe is more energy efficient, cost effective, and sustainable than ductile iron (DI) pipe. DIPRA maintains that DI pipe has lower pumping costs than PVC pipe. The claim is that DI's larger inside diameters (ID) offset PVC's better flow characteristics. However, DIPRA's brochures and on-line calculator contain misleading information and erroneous hydraulic assumptions, generating biased results.

COMPARING PIPE HYDRAULICS: THE IMPORTANCE OF EQUIVALENT PRESSURE CLASS AND A DECLINING "C" FACTOR FOR DI PIPE

#1: Inside Diameter

In documents such as "Hydraulic Analysis of Ductile Iron Pipe,"[1] DIPRA compares different pressure classes (PC) of DI and PVC pipe. Moreover, the DI pipe selected is the largest ID (thinnest walled) available but is not commonly used in design and construction. Instead, an equivalent PC should be considered. For example, DIPRA compares DI PC200 pipe to a higher pressure class PVC PC235 pipe. For an accurate comparison, PVC and DI pipe should have the same pressure class: PC200. PVC PC200 has a larger ID than PVC PC235, thus reducing the ID difference DIPRA promotes.

Given that corrosive soils affect approximately 75% of the US, choosing adequate corrosion allowance (extra wall thickness) for DI pipe is critical. Refer to "Iron Pipe Wall Thickness – Thinner and Thinner"[2] (click here to view) and "Iron Pipe Corrosion – Lessons Learned"[3] (click here to view) for more information.

Utilities are often concerned about corrosion and specify a minimum thickness class to provide a corrosion allowance when designing with DI pipe. PVC pipe is not subject to corrosion and therefore does not require additional wall thickness. PVC pipe wall thickness requirements are based on the pressure class of pipe needed to meet the pressure design of the system.

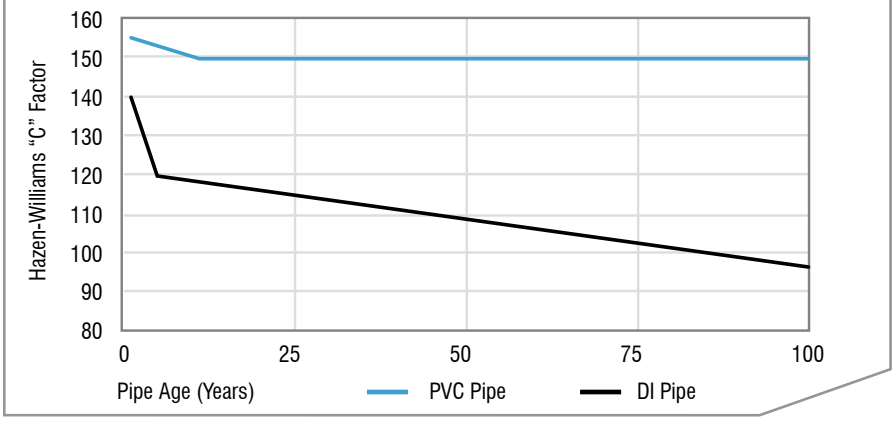
When design engineers choose a pipe wall thickness for DI pipe based on pressure requirements and corrosion considerations, the ID advantage claimed by DIPRA is diminished or eliminated. The ID can be further reduced by the thickness of cement-mortar lining required.

#2: Flow Characteristics Over Time

Studies have shown that PVC pipe has an initial Hazen-Williams "C" value of 155-165 that may decrease to 150 over the life cycle of the pipe. DIPRA uses a "C" value of 150 for PVC pipe.

For DI pipe, DIPRA uses a constant value for "C" of 140 over the design life of a pipeline. This assumption has been shown to be incorrect by DIPRA's own data and by other research on the subject. Studies show that DI pipe has an initial "C" value of 140 that continually decreases with time. Pump station design confirms this by taking into consideration a pipe's flow coefficient decline to ensure continued capacity over the life of pressurized pipelines. Additionally, the DI pipe industry offers "double thickness" cement-mortar lined pipe, further confirming that its linings deteriorate. For comparison, 24-inch steel and concrete pressure pipes use

FIGURE 1: "C" VALUES FOR PVC AND DI PIPE PER SSC STUDY

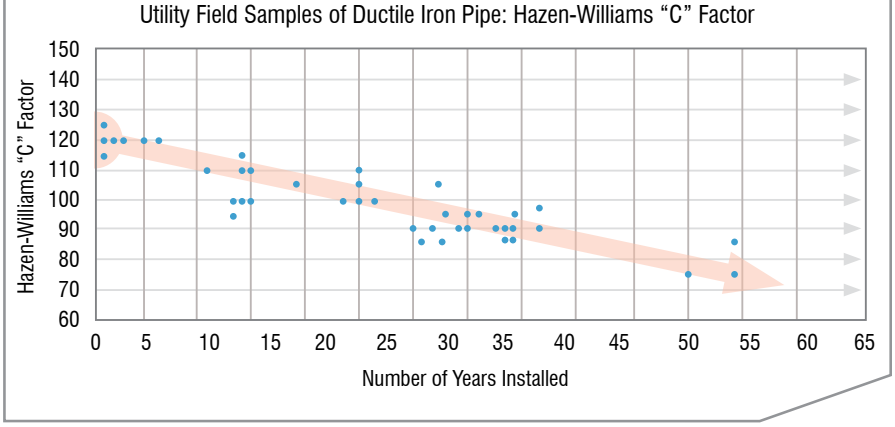


cement-mortar lining thicknesses from 4 to 16 times greater than DI pipe. Therefore, for an unbiased hydraulic comparison, the "C" factor for DI pipe should not be constant, but rather should decline with time. More information on this topic can be found in the Uni-Bell PVC Pipe Association (PVCPA) Tech Brief titled "Ductile Iron Pipe's Hazen-Williams Flow Coefficient Declines Over Time"[4] (click here to view).

The "Life Cycle Assessment of PVC Water and Sewer Pipe and Comparative Sustainability Analysis of Pipe Materials"[5] report by Sustainable Solutions Corporation (SSC) analyzed "C" factor deterioration for pipe materials over a 100-year design life (click here to view). The report assigns an initial "C" value of 155 for PVC pipe which declines to a value of 150. The SSC study shows that DI experiences a rapid initial decline from a "C" value of 140, then a gradual degradation rate thereafter. The gradual "C" factor decline in the SSC study of 2.5 per decade is consistent with the City of Detroit's findings published in its "Comprehensive Water Master Plan"[6] developed by CDM Smith and CH2M Hill (click here to view). Figure 1 shows the "C" value deterioration for PVC and DI pipe over a 100-year design life. Detroit's analysis shows that the pumping efficiency for DI pipe continually declines with age and does not remain at factory specifications.

Detroit's degradation rate for DI pipe's cement-mortar lining is better than found in many other studies. However, the decline in DI's pumping efficiency can be much worse. As shown in Figure 2, field samples of over 60 mortar-lined DI pipes from the Western Virginia Water Authority demonstrate how the "C" factor decreased from 125 to 75 over a 55-year timeframe. The Washington Suburban Sanitary Commission provided 27 iron pipe field data samples which show a similar trend.[7,8] Design conditions may need to take into consideration greater declines in the Hazen-Williams "C" factor for DI pipe.

FIGURE 2: FIELD SAMPLES SHOWING DECLINING "C" FACTOR FOR DI PIPE



HIGHLIGHTS FROM PVCPA TECH BRIEF "DUCTILE IRON PIPE'S HAZEN-WILLIAMS FLOW COEFFICIENT DECLINES OVER TIME" (click here to view)

A significant body of research and studies document "C" factor deterioration for DI pipe:

- A DIPRA brochure titled "Cement-Mortar Linings for Ductile Iron Pipe"[9] recommends "C" to be 140 for the life of the DI pipe. However, data in the same document show that for eight DI-using cities, "C" deteriorates between 0.22 and 0.46 annually (see Figure 3).

- Other studies show similar, even more dramatic results (see Figure 4). Additionally, a 2017 study from Virginia Tech University states: "The assumption of the head loss being constant for DI pipe throughout the life is an incorrect assumption. The Hazen-Williams factor and the effective diameter decrease with time due to internal corrosion and tuberculation in the DI pipe."[10]

FIGURE 3: "C" VALUES FOR DI PIPE / DIPRA BROCHURE

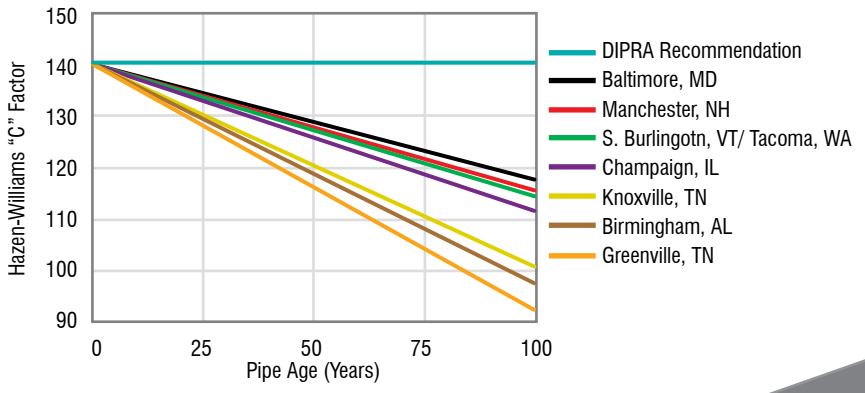
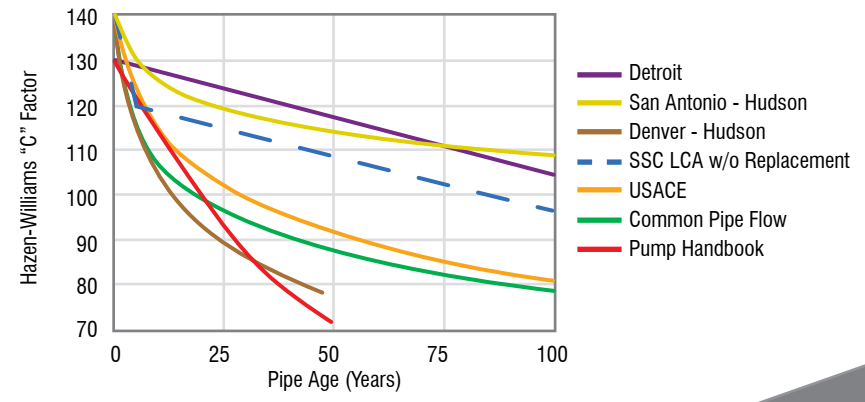


FIGURE 4: "C" VALUES FOR DI PIPE / STUDIES



AN UNBIASED HYDRAULIC ANALYSIS OF PVC AND DI PIPE

#1: Inside Diameter

As discussed earlier, to be accurately compared, both PVC and DI pipes should have the same pressure class: PC200. Therefore, DI PC200 pipe should be compared to PVC PC200 (DR21) pipe, not to PVC PC235 (DR18) pipe as done by DIPRA.

#2: Hazen-Williams "C" Factor

To accurately calculate flow characteristics over time, correct "C" values for pipe must be used. As shown, for PVC pipe its "C" value remains at 150 after an initial decline from 155. For this analysis, the "C" factors for DI pipe are based on the SSC report (see Figure 1 and blue dashed lines in Figure 4). DI pipe's "C" value declines at an annual rate of 0.25 after an initial decline from 140. Figures 3 and 4 show that DI pipe's degradation rate can be much worse.

CORRECTED PARAMETERS TELL A DIFFERENT STORY: DESIGN EXAMPLE

DIPRA's design example from "Hydraulic Analysis of Ductile Iron Pipe"[1] uses these assumptions:

- Pipe diameter: 24-inch nominal
- Pipeline length: 30,000 feet
- Design flow: 6,000 gpm
- Unit power cost: $0.10/kWh
- Pump operating efficiency: 70%
- Pump operating time: 24 hours per day
- Design life: 100 years

The analysis is recalculated below using the correct PC and inside diameter for PVC pipe and a realistic Hazen-Williams "C" factor for DI pipe. To be consistent with the DIPRA example, a 100-year design life is used for both materials. However, the service life of DI pipe has been found to be significantly less than the 100-year life of PVC:

DI pipe service-life:

- The SSC report cites numerous studies showing a 50-year service life for DI pipe.[11]
- A Water Research Foundation report found that in moderately corrosive soils, DI pipe will last only 11-14 years.[12]

PVC pipe service-life:

- Dig-ups and testing over the last 60 years confirm the longevity of PVC pipe to be in excess of 100 years. [13, 14]
- Studies show that PVC has the lowest water main break rate of the most commonly used pipe materials. [15, 16]

HEAD LOSS

In this example, for the first three years DI pipe has slightly better flow characteristics than PVC pipe of the same pressure class. However, the decline in DI's hydraulic characteristics soon causes the situation to reverse.

$$H_L = 1{,}000 \left[\frac{V}{0.115C(d)^{0.63}} \right]^{1.852}$$

$$V = \frac{Q}{2.448d^2}$$

H_L = Head loss (ft./1,000 ft.)
V = Velocity (fps)
C = Flow coefficient ("C" Value)
Note: "C" value changes with pipe age (see Figures 1-4)
d = Inside diameter (in.)
Q = Flow (gpm)

TABLE 1: COMPARISON OF VALUES FOR 24" PVC AND DI PC200 PIPE

	PVC	Ductile Iron
Inside Diameter (in.)	23.20	24.95
"C" Value	155 – 150*	140 – 96**

*"C" Value for PVC decreases from 155 to 150 then remains constant
**"C" Value for DI initially decreases rapidly from 140 then decreases at a constant rate of 0.25/year

To determine total head loss over the life of the pipe, an average head loss calculation must be computed for each year using the appropriate "C" factor. The total head loss over the design life is then the sum of the average yearly head losses. Below are highlights of the head loss calculations.

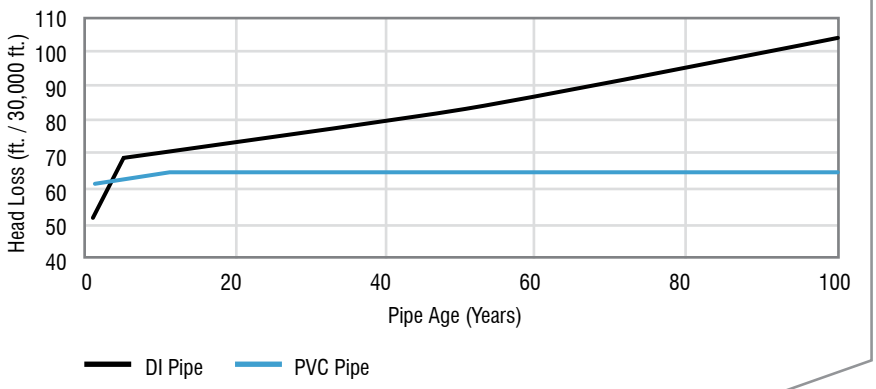
- **Year 1:** Using the same design equations as DIPRA, the head loss for 24-inch DI PC200 pipe is 1.73 ft./1,000 ft. With the same analysis method, head loss for 24" PVC PC200 pipe is 2.04 ft./1,000 ft.

- **Year 4:** The "C" value for DI pipe has declined causing DI's head loss to be 2.13 ft./1,000 ft., greater than PVC pipe's head loss of 2.08 ft./1,000 ft.

- **Year 100:** If DI pipe were not already replaced due to corrosion, DI's "C" value will have deteriorated to just over 96 resulting in a head loss of 3.46 ft./1,000 ft., about 60% higher than PVC pipe's head loss of 2.17 ft./1,000 ft.

These results show that when an unbiased comparison is undertaken over the design life of a pipeline, PVC's design head loss is less than DI pipe's. Figure 5 shows the anticipated head loss for the 24-inch 30,000 ft. pipeline and illustrates the effect of the deterioration of DI's "C" factor.

FIGURE 5: HEAD LOSS FOR DI AND PVC PIPE



PUMPING COSTS

Using the design example's parameters, including "C" value deterioration, the pumping costs over a 100-year period for a 30,000 ft. DI PC200 pipeline would be $11.8 million. For a 30,000 ft. PVC PC200 pipeline, the total pumping costs over a 100-year period would be only $9.2 million (see Figure 6).

$$C_P = 1.65 H_L Q \frac{a}{E}$$

C_P = Pumping cost ($/yr. based on 24-hr./d pump operation/1,000 ft.)
H_L = Head loss (ft./1,000 ft.)
Q = Flow (gpm)
a = Unit cost of electricity ($/kWh)
E = Total efficiency of pump system (%/100)

FIGURE 6: CUMULATIVE 100-YEAR PUMPING COSTS COMPARISON FOR 24" PVC AND DI PC200 PIPE*

*Rising cost of electricity not included. If this was taken into account, the cost savings using PVC pipe would be even greater.

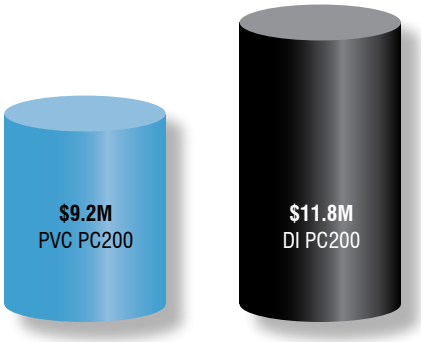


FIGURE 7: ANNUAL PUMPING FOR DI AND PVC PIPE

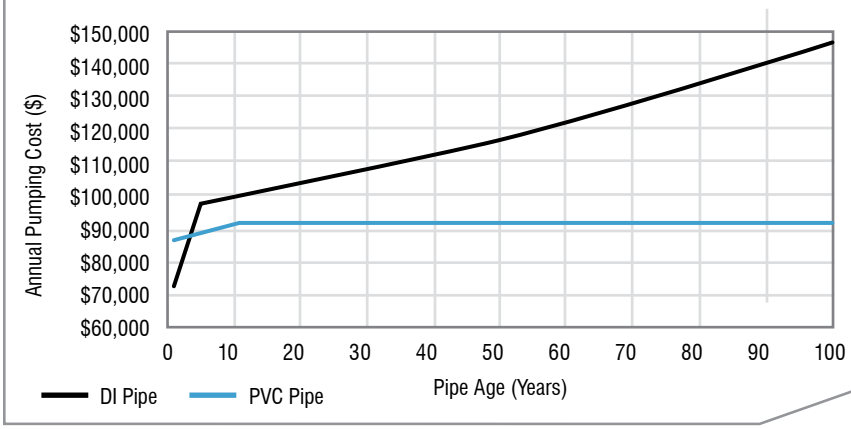


Figure 7 shows the annual pumping costs for the 30,000 ft. pipeline. As with the head loss calculations, to determine total pumping cost over time, pumping cost must be computed for each year using the corresponding annual head loss. The pumping cost over the design life is then the sum of the yearly pumping costs. The average annual pumping cost is the total pumping costs divided by the design life. Below are highlights of the calculations. The 100-year average annual costs would be:

- For DI PC200 pipe: $118,000 (ranging from $73,300 to $146,600)
- For PVC PC200 pipe: $91,700 (ranging from $86,500 to $91,900)

DI pipe's 100-year average annual cost would be $26,300 greater than PVC.

PVC PIPE HAS LOWEST PUMPING COSTS

This paper addresses the inaccurate hydraulic claims made by the Ductile Iron Pipe Research Association (DIPRA) and shows that when industry-accepted data are used, PVC pipe is more energy efficient, cost effective, and sustainable than ductile iron (DI) pipe. The claim is that DI's larger inside diameters (ID) offset PVC's better flow characteristics. However, DIPRA's brochures and on-line calculator contain misleading information and erroneous hydraulic assumptions, generating biased results.

PVCPIPE association

REFERENCES

1 DIPRA website brochure: "Hydraulic Analysis of Ductile Iron Pipe" (2016)

2 PVCPA Technical Brief: "Iron Pipe Wall Thickness – Thinner and Thinner" (2016)

3 PVCPA Technical Brief: "Iron Pipe Corrosion – Lessons Learned" (2017)

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9 DIPRA website brochure: "Cement-Mortar Linings for Ductile Iron Pipe" (2017)

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