

Strength and **Durability** for **LiFe®**



MATERIAL COMPARISONS

Ductile Iron Pipe vs. PVC

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The key to value in pipeline projects is to design and install those pipelines to minimize maintenance and optimize longevity. To accomplish this, it is important to understand the strengths and weaknesses of different pipe materials so that designs can better focus on achieving a desired service life.

To make that job easier, this brochure will present the engineering and performance attributes of Ductile iron pipe and how they compare and contrast with PVC pipe. In doing so, we will provide useful information that will help engineers design and specify pipe with a complete understanding of how to maximize performance—and appreciate why Ductile iron pipe provides the best long-term value.

In addition to providing physical test data for the two pipe products, we will compare applicable AWWA standards for each pipe. We will also examine the history of PVC pipe standards and how they have relaxed their requirements over the years.

Lastly, we will provide comparisons. We will compare proper installation practices based on the different ways the two pipe materials perform, and discuss operational aspects such as failure modes and relative headloss in Ductile iron and PVC pipes based on field-conducted flow tests for the two pipes in the same system.

The data provided were drawn from several sources, including AWWA standards, published information from pipe manufacturers and associations, and physical testing performed by research engineers from the Ductile Iron Pipe Research Association, M.E. Simpson Company, and the Robert W. Hunt Company. In short, this brochure will present sound engineering

information that will demonstrate, convincingly, a singular fact: Ductile iron pipe is the right decision.

PVC's History of Reducing Safety Factors

Engineers have asked, with good reason, why PVC pipe standard revisions have incorporated major changes in design and testing requirements. When ANSI/AWWA C900 (“AWWA C900”) was introduced, it covered PVC pipe up through 12 inches in size and was designated as a standard for “distribution pipe” (AWWA C900, 1975). The design incorporated a safety factor of 2.5 that was applied to the sum of the working pressure and a surge allowance. Because surge pressures were part of the design, AWWA C900 PVC pipe was defined in the original standard as a “Pressure Class” pipe. Thus, in those first AWWA C900 standards, DR 18 PVC was designated as Pressure Class 150 pipe and with the surge allowance, had a pressure rating of 185 psi.

When the ANSI/AWWA C905 (“AWWA C905”) standard debuted, it covered pipe 14 inches through 36 inches, which was expressly designated in the title as being a standard for transmission mains (AWWA C905, 1988). Those transmission mains were rationalized as needing less stringent design criteria than the distribution pipe in AWWA C900, so the factor of safety was reduced from 2.5 to 2.0 and surge pressures were excluded from the design. Those pipes

were defined as “Pressure Rated” pipes, which gave AWWA C905 DR 18 PVC a pressure rating of 235 psi. At the time, according to one PVC pipe manufacturer, the reduced safety factor and elimination of the surge allowance were justified because the pipe was “intended for use as water transmission piping where long straight runs are the norm and system geometry is more simplistic. Surge pressures are easily predictable and should be accounted for in design” (J.M. Eagle, 2022) (Pacific Plastics, Inc., 2017).

So, from 1975 to 2007, AWWA C900 PVC pipe was designated as a pressure class pipe that incorporated a surge allowance in its design and included a nominal safety factor of 2.5. Thirty-two years later, the 2007 revision to the AWWA C900 standard (3- through 12-inch PVC) reduced the safety factor from 2.5 to 2.0 and removed the surge pressure allowance from the design. So, the PVC pipe industry decided to treat their distribution pipe the same way it had treated transmission mains, ignoring the justification originally expressed for having two design approaches.

In 2016 AWWA C900 was modified and combined with AWWA C905 and the AWWA C905 standard was retired.

Pressure Class vs Pressure Rated

According to a researcher for a major manufacturer of PVC pipe, “(t)he weakness of PVC pipe is its limited resistance to surging pressure,” (Hucks, R.T., 1972). Whereas AWWA C900-97 PVC had an allowance for surge pressure, AWWA C900-16 PVC pipe has no allowance for surge pressure in the pressure ratings.

So, the total internal design pressure in AWWA C900-16 is less than the total internal design pressure in AWWA C900-97.

Add the reduction in safety factor from 2.5 to 2.0 and:

AWWA C900-97 DR 18 PVC = “Pressure Class 150”
AWWA C900-16 DR 18 PVC = “Pressure Class 235”

These two pipes are haven’t changed—they are exactly the same PVC material and exactly the same wall thickness, but the reduction in safety factor and removal of surge allowance allows the PVC pipe industry to print a new, higher value for pressure on the side of their pipe. This implies they would promote using lower classes of pipe at higher working pressures. The problem is, that using lower classes of pipe at higher working pressures magnifies the increase in stress in the thinner wall of the pipe; and stress is what causes PVC pipe to fail.

The net effect of this reduction in conservatism in the PVC pipe design is that some PVC pipelines will be subjected to higher stresses than they would have if the standard had not been weakened. Table 1 highlights examples of shortcomings in the AWWA C900-17 standard and compares them to the requirements found in ANSI/AWWA C150/A21.50 and ANSI/AWWA C151/A21.51 standards for Ductile iron pipe.

PVC Pipe Failure Mechanisms

PVC pipe fails under an applied stress over time. The higher the stress, the sooner the pipe fails. According to the WRF Report #4680 “(t)he most common problems that lead to failures in plastic pipe relate to material handling and installation and environmental factors including excessive deflection, joint misalignment and/or leakage, poor service connection installations, longitudinal breaks from stress, exposure to sunlight, high system pressure, pressure surges, exposure to solvents, and damage caused from tapping (WRF 4680, 2016, p. 9).”

TABLE 1
Comparison of Ductile Iron Pipe and PVC Pipe Standards

Topic	Ductile iron pipe ANSI/AWWA C150/A21.50 ANSI/AWWA C151/A21.517 ANSI/AWWA C151/A21.51 ⁷	PVC Pipe ANSI/AWWA C900-16
Sizes	3" – 64"	4" – 60"
Laying Lengths	18' or 20'	20' ± 1'
Pressure Class/ Ratings	Rated up to 350 psi. Pressure Class 150, 200, 250, 300, & 350. Higher pressures may be designed.	Rated at 80, 100, 125, 150, 165, 200, 235, 250, & 305 psi (DRs 51, 41, 32.5, 27.5, 25, 21, 18, 17, & 14, respectively) at a service temperature of 73.4°F. For service temperatures greater than 73.4°F, the pressure ratings must be appropriately reduced.
Method of Design	Designed as a flexible conduit. Separate design for internal pressure (hoop stress equation) and external load (bending stress and deflection). Casting tolerance and service allowance added to net thickness.	Designed as a flexible conduit. Separate design for internal pressure (hoop stress equation) and external load (deflection) — external load is not covered by a standard. No consideration for bending stress, neither for longitudinal nor ring bending.
Internal Pressure Design	Stress due to working pressure plus surge pressure cannot exceed the minimum yield strength of 42,000 psi and a 2.0 safety factor.	Stress due to working pressure alone. Based on a Hydrostatic Design Basis of 4,000 psi and a 2.0 safety factor (HDS = 2,000 psi).
Surge Allowance	Nominal surge allowance is 100 psi (based on an instantaneous velocity change of approximately 2 fps); however, actual anticipated surge pressures should be used.	None included. Surges are treated as transients that are handled by the quick-burst strength of PVC. For non-transient surges, pressure ratings must be reduced. Pressure surges based on an instantaneous velocity change of 2 fps would be 30, 35, & 40 psi for DRs 25, 18, & 14, respectively..
External Load Design	Prism load + truck load. Ring bending stress limited to 48,000 psi, which is 1/2 the minimum ultimate bending strength. Deflection is limited to 3% of the outside diameter of the pipe, which is 1/2 of the deflection that might damage the cement-mortar lining.	No thickness design standard for PVC pipe. The installation standard, ANSI/AWWA C6058, places a limit of 5% on vertical cross-section deflection. Reference is made to AWWA M239 for design procedures. Prism load + truck load. Utilizes the Modified Iowa Deflection Equation; however, no safety factors are defined.
Live Load	AASHTO H-20, assuming a single 16,000-lb concentrated wheel load. Impact factor is 1.5 for all depths.	Design not covered in the standard. Reference is made to AWWA M23 for design procedures. AASHTO H-20, 16,000-lb wheel load. Impact factor of 1.1 for depths of cover between 2 and 3 feet. Impact factor of 1.0 for depths of cover of 3 feet or greater.
Factor of Safety	Pressure Design: 2.0 (including surge) based on a minimum tensile yield strength of 42,000 psi. External Load Design: 2.0 for bending based on a minimum ultimate ring bending strength of 96,000 psi. 2.0 for deflection based on the flexibility of the cement-mortar lining. Note: Actual safety factors are greater than the nominal safety factors due to the addition of the service allowance and the allowance for the casting tolerance that are part of the standard design described in AWWA C150.	Pressure Design: 2.0 (no surge included) based on the Hydrostatic Design Basis (HDB). In case of surge, the 2.0 safety factor is allowed to be compromised to as low as 1.25. For recurring surge the design is based on the mean stress, stress amplitude, number of cycles to failure and the design life of the pipe. External Load Design: No safety factor can be calculated. No external load criteria are defined. Note: Safety factors and strength greatly affected by temperature, surface scratches, cyclic pressure fluctuations, and extended exposure to sunlight. Pipes under cyclic loadings are likely to have lower inherent factors of safety than those under static loading.
Standard Laying Conditions	Five standard laying conditions (Types 1 through 5) based on conservative E' and soil strength parameters listed. Type 1 (flat bottom trench with loose backfill or Type 2 (flat bottom trench with backfill lightly consolidated to pipe centerline) are adequate for most applications	The forward of AWWA C900 references AWWA Manual M23 and ANSI/AWWA C605. C605 lists five trench conditions referred to as "common embedment types." These trench types resemble the trench types for Ductile iron pipe design, but they assume less conservative values for the bedding constant (K) and the soil modulus (E') for the commonly used PVC trench types.

That's some 10 different ways for PVC pipe failures to be considered "common" failures. These failure modes are all related to stress and highlight the fact that PVC pipe's service life is a function of the stress the pipe experiences—especially localized or differential stresses.

The design of PVC pipe is based on a Stress-Regression curve that is a plot of failure points resulting from the application of a hydrostatic internal pressure over time (see Figure 5). To increase the service life of PVC pipe, one must control the stress the pipe experiences. As this brochure will explain, it takes a significant effort in design and installation to control the stress on PVC pipe.

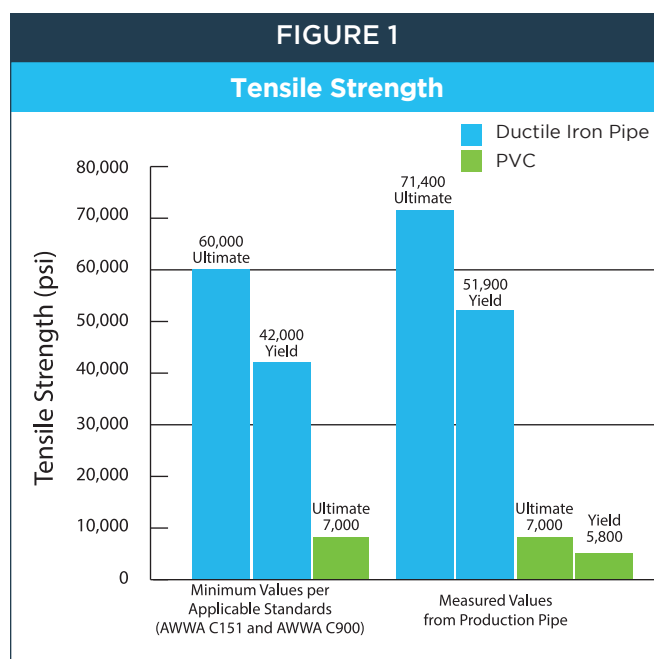
Ductile Iron Pipe has More Than Eight Times the Tensile Strength of PVC

The pipe material's tensile strength is a very important basic property because it resists the forces caused by internal hydrostatic pressure and water hammer.

Figure 1 compares the tensile strengths of Ductile iron pipe and PVC pipe. Shown for comparison are minimum values per the applicable standards, as well as test data from actual measurements of specimens taken from the wall of 6-inch Pressure Class 350* Ductile iron pipe and 6-inch DR 18 (PC 235, previously PC 150) PVC pipe.

Typical Variations in Operating or Installation Temperature Do Not Affect the Strength of Ductile Iron Pipe

Because Ductile iron pipe has a moderate and dependable coefficient of thermal expansion, few problems result from changes in service temperatures. In a typical range of waterworks operating temperatures (32°F to 95°F) or even a conceivable range of installation temperatures (-10°F to 110°F), there is no significant difference in the tensile strength of Ductile iron pipe.

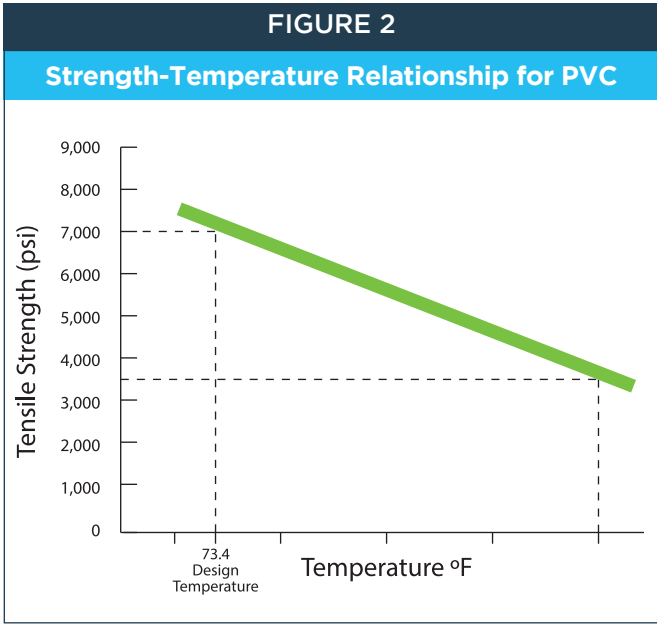


*Pressure Class 350 is the lowest available pressure class for 6-inch Ductile iron pipe.

On the other hand, PVC pipe has a high thermal expansion coefficient. The performance of PVC pipe is significantly related to its operating temperature. For service at temperatures greater than 73.4°F, PVC loses tensile strength, pipe stiffness, and dimensional stability (M23, 2020, Table 5-1; Uni-Bell, 2017, Table 5.3; C900, 2017, Table 3). Thus, "the pressure capacity of the PVC pipe is reduced and more care must be taken during installation to avoid excessive deflection" (M23, 2020, p. 7).

Conversely, at temperatures less than 73.4°F, PVC loses impact strength and flexibility, "necessitating greater handling care in colder weather" (M23, 2020, p. 6). Because the thermal expansion coefficient of PVC is approximately five times that of Ductile iron pipe it is conceivable that, when exposed to extreme temperature changes, PVC pipe will experience undesirable structural movements such as joint buckling or disengagement because of expansion or contraction.

Figure 2 shows the relationship based on the standard tensile strength of 7,000 psi for PVC with no stress applied. At 110°F, the tensile strength of PVC is half of the tensile strength at 73.4°F and the pressure capacity of PVC pipe should be multiplied by 0.50 (AWWA C900, 2017, Table 3).



Ductile Iron Pipe Resists up to Four Times the Hydrostatic Burst Pressure of PVC Pipe

The burst test is the most direct measurement of a pipe material’s resistance to internal pressure. Figure 3 compares the average burst pressures of 6-inch Pressure Class 350¹ Ductile iron pipe and 6-inch DR 18 (PC 235) PVC pipe. Note that Ductile iron pipe is available in pressure classes up to 350 psi in all sizes, 3-inch through 64-inch. Pressure Class 350 Ductile iron pipe corresponds to a total pressure rating of 450 psi, including a 100-psi surge allowance. No PVC pipe is manufactured with a total pressure rating as great as that of Ductile iron pipe.

¹ Pressure Class 350 is the lowest available pressure class for 6-inch Ductile iron pipe.

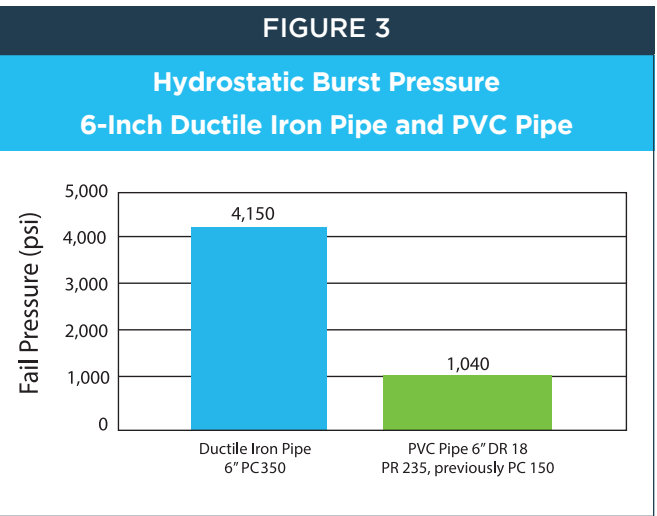
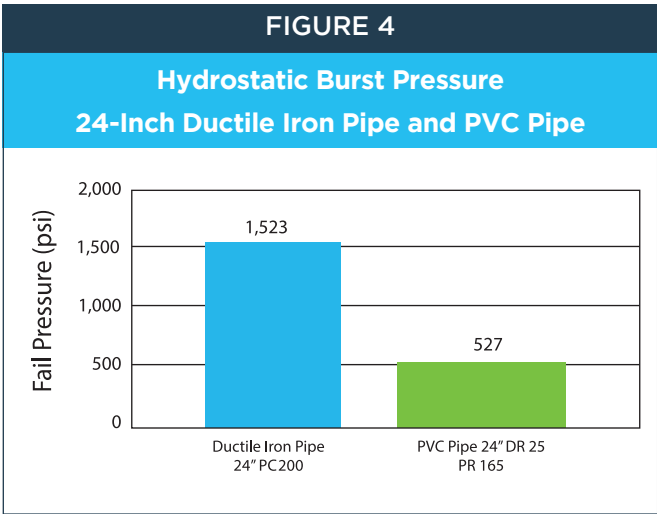


Figure 4 compares the hydrostatic burst pressure of 24-inch Pressure Class 200² Ductile iron pipe and 24-inch DR 25 (PC165) PVC pipe. In laboratory tests, the average burst pressure of the 24-inch Ductile iron pipe was 1,523 psi. For the PVC pipe, it was 527 psi—one-third that of Ductile iron pipe.



² Pressure Class 200 is the lowest available pressure class for 24-inch Ductile iron pipe.

The Strength of Ductile Iron Pipe is Not Compromised by Time

With Ductile iron pipe, there is no measurable relationship between applied stress and time to failure. The allowable stress for hydrostatic design of Ductile iron pipe is its minimum yield strength in tension, 42,000 psi.

PVC responds to stress by failing after a period of time inversely related to the applied stress. Thus, the strength used for hydrostatic design of PVC pipe is less than the yield strength of the material as established in a short time test (Uni-Bell, 2012, Fig. 5.6). The strength value used is the long-term hydrostatic strength and is referred to as the Hydrostatic Design Basis (“HDB”).

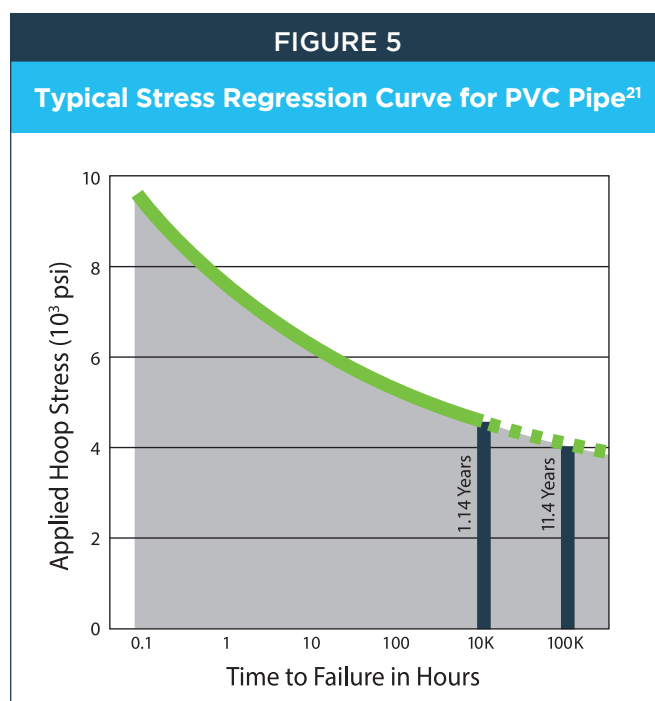
The HDB value, which is defined as the stress that results in failure after 100,000 hours (11.4 years), is determined according to ASTM standard procedures by extrapolation from data accumulated from tests lasting up to 10,000 hours (1.14 years) (ASTM D2837, 2022). For the PVC compound used in C900, the HDB is 4,000 psi (M23, 2020, p 2) at 73.4°F. The HDB will be less than 4,000 psi for PVC pipe used at temperatures greater than 73.4°F (M23, 2020, p 6).

Since no utility wants its pipe to last only 11.4 years, a nominal factor of safety is applied to the HDB. The nominal factor of safety depends upon the standard under which the pipe was manufactured. For AWWA C900-97, the factor of safety was 2.5 (AWWA C900, 1997). For AWWA C900-07 and subsequent revisions, the factor of safety is 2.0 (AWWA C900, 2007; AWWA C900, 2016). This design is based strictly upon hydrostatic pressure and does not take into account any stresses that result from external loads, deflection of joints, bending of the pipe to change direction, restrained joint engagement and other localized stresses that may occur

during installation or in operation over time, nor do they account for cyclical fluctuations in pressure. Yet these factors may have a significant effect on the service life of the pipe.

Figure 5 is a typical stress regression curve for PVC pressure pipe (M23, 2020, Figure 5-1). The stress regression curve is a plot of failure points that demonstrates PVC’s ability to withstand stress as a function of the magnitude of the stress and the length of time that stress is applied. Thus, the stress regression curve is a plot of the length of time to failure at various levels of stress. As the curve shows, the higher the stress the shorter the expected life for PVC pipe.

It is also important to note that the stress regression curve shown in Figure 5 was obtained by only testing sections of the barrel of PVC pipe. As described later, the joints are one of the common failure points for PVC pipe and they were not included in the tests used to determine the HDB for PVC pipe.



Ductile Iron Pipe Resists Up to Eight Times the Crushing Load of PVC Pipe

The different theories of design of buried pipelines become most significant in relation to external load design. Both Ductile iron pipe and PVC pipe, being flexible conduits, respond to external load by ring deflection (AWWA C150, 2014; M23, 2020, Chapter 4). The interaction of the deflected ring with the surrounding soil is the complex question in the design theories.

The design procedure for Ductile iron pipe is based on limiting both the ring bending stress and ring deflection, while the only parameter used in the design of PVC pipe is ring deflection.

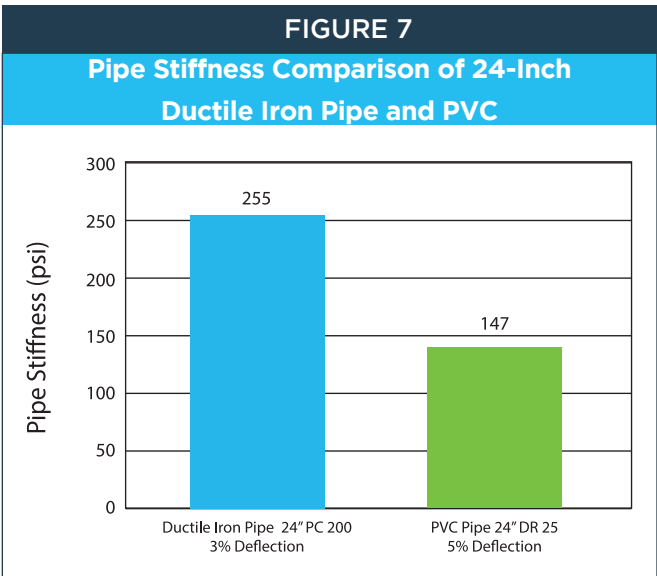
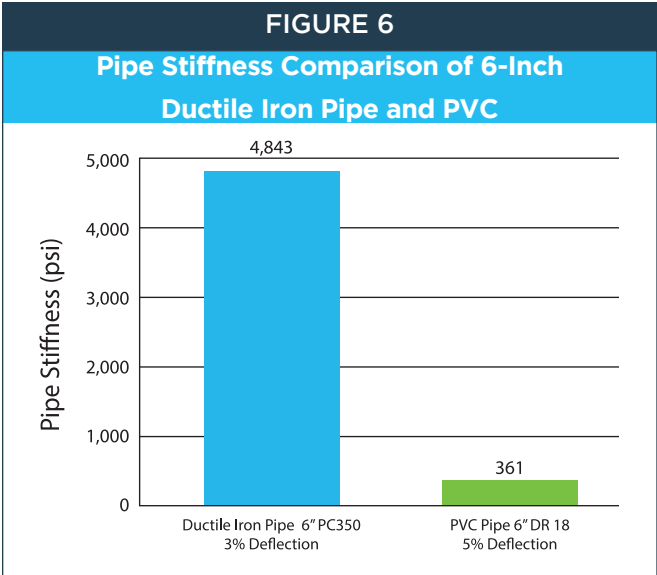
The standard design procedure for Ductile iron pipe limits the ring deflection due to external loads to 3 percent. This limit, which is based on the performance limit for cement-mortar linings typically specified for Ductile iron pipe, includes an explicit safety factor of 2. The calculation employs the same conservative assumptions regarding soil parameters and earth loads used in the bending stress calculation.

The usual design procedure for PVC limits ring deflection to 5 percent (M23, 2020, p 29)—the only consideration given to external loading.

Both Ductile iron pipe and PVC pipe design procedures employ the Iowa formula to predict deflection of the pipe (Uni-Bell, 2012, pp. 7.12-7.14). In the Iowa formulation, both pipe stiffness and the stiffness of the fill material around the pipe contribute to limiting the deflection. Because PVC is susceptible to differential stresses that result from installation errors, the importance of soil stiffness is greater for PVC. To limit stress in the wall of PVC pipe under earth and traffic loads, the pipe backfill can be designed for maximum support. This means that with PVC pipe, bedding conditions and

on-the-job installation inspection are much more important.

The parallel plate ring crush test provides a simple comparison of the relative strengths of the two piping materials. Figure 6 compares pipe stiffness resulting from such tests conducted on 6-inch Pressure Class 350³ Ductile iron pipe and 6-inch DR 18 PVC pipe. Likewise, Figure 7 compares pipe stiffness for 24-inch Pressure Class 200⁴ Ductile iron pipe and DR 25 PVC pipe.

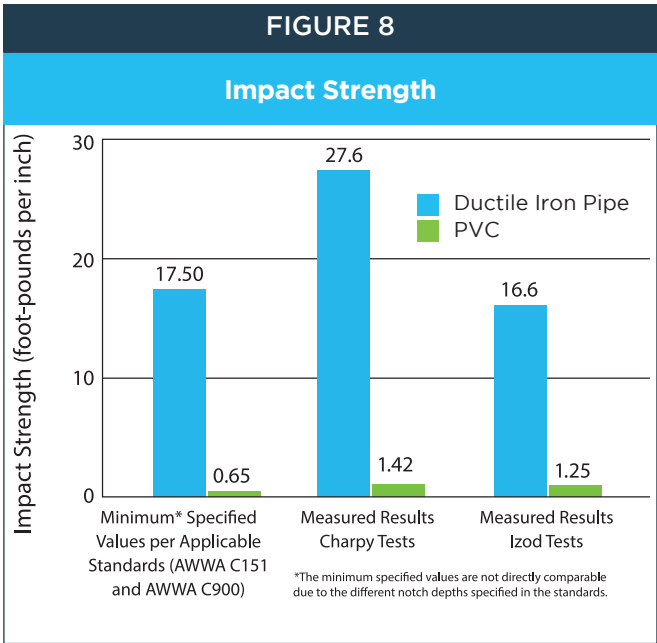


³ Pressure Class 350 is the lowest available pressure class for 6-inch Ductile iron pipe.

⁴ Pressure Class 200 is the lowest available pressure class for 24-inch Ductile iron pipe.

Ductile Iron Pipe has More Than 13 Times the Impact Strength of PVC

Impact strength is another important characteristic of piping materials. While this property relates more to conditions the pipe might encounter during handling, shipping, and installation, it is nevertheless important because damage incurred during these activities can go undetected and later result in failures in the operating pipeline. Figure 8 compares the impact strength as specified and measured for Ductile iron pipe and PVC, which were tested by both the IZOD (cantilevered beam) and Charpy (simple beam) methods (ASTM E23, 2018). These values are representative of tests conducted at 73.4°F. As with tensile strength, there is no measurable relationship between impact-resistance and temperature within expected ranges for Ductile iron pipe. PVC pipe, however, exhibits a measurable decrease in impact strength at temperatures below 73.4°F (M23, 2020, Figure 1-2). The impact strength of PVC is also measurably decreased after the pipe has been overexposed to sunlight—an important consideration in storing PVC pipe stocks (M23, 2020, p 8).



Direct Tapping Ductile Iron Pipe is Easier, less Expensive, Faster—and Less Likely to Damage the Pipe—Than Tapping PVC

DIPRA conducted tests comparing several different parameters concerned with the direct tapping of 5-foot lengths of 6-inch Pressure Class 350 Ductile iron pipe and 6-inch DR 14 (PR 305, previously PC 200) PVC pipe, including leak tests, pull-out tests, and cantilever load tests (DIPRA, 1987). Each material was tapped according to the manufacturer’s directions by the same machine operator. The results follow.

Leak Tests

For each pipe material, a tap was made at 50 psi internal pressure. Pressure was then increased in 25-psi increments to each pipe’s maximum pressure class at the time (350 psi for Pressure Class 350 Ductile iron pipe and 200 psi for DR 14 PVC).

The 2007 revision of AWWA C900 reduced the safety factor from 2.5 to 2.0, resulting in the same DR 14 Pressure Class 200 pipe now being rated at 305 psi. The higher internal pressures now allowed for DR 14 pipe will likely result in more leakage for PVC pipe than was reported for these tests.



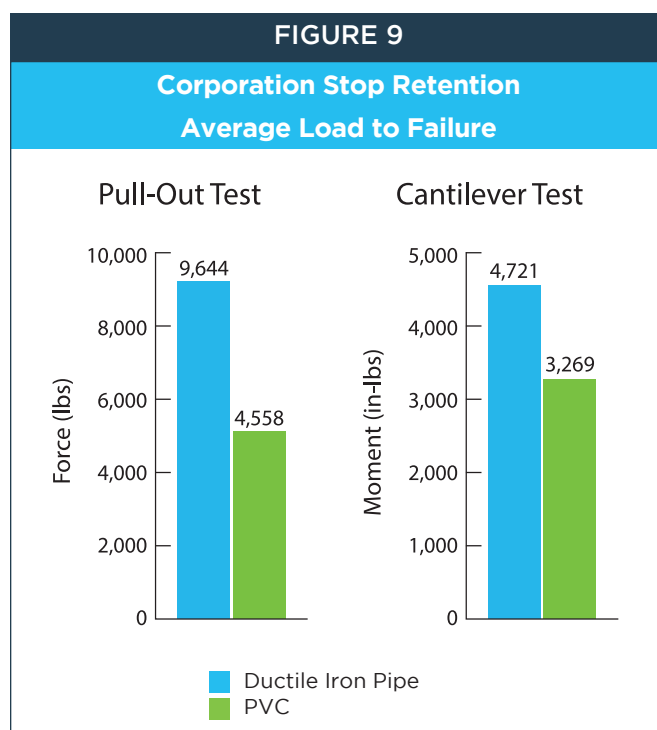
Eight 3/4-inch taps were made on five PVC pipe specimens. The corporation stops were torqued to 27 ft-lbs according to the manufacturer's directions. Of the eight direct taps, five leaked prior to reaching the final 200 psi internal pressure. All leakage occurred at the threaded connection of the PVC pipe and corporation stop. Each of the five leaking connections was retorqued to 35 ft-lbs and internal pressure was increased. Each of these connections continued to leak prior to the pipe's 200 psi working pressure.

According to the *PVC Pressure Pipe Tapping Guide*, if a leaking direct tap in PVC pipe continues to leak after the corporation stop torque is increased to 35 ft-lbs, the pressure in the water main should be relieved, the corporation stop removed, threads inspected and cleansed, and the corporation stop reinstalled and rechecked (UNI-PUB-08-21, p. 16).

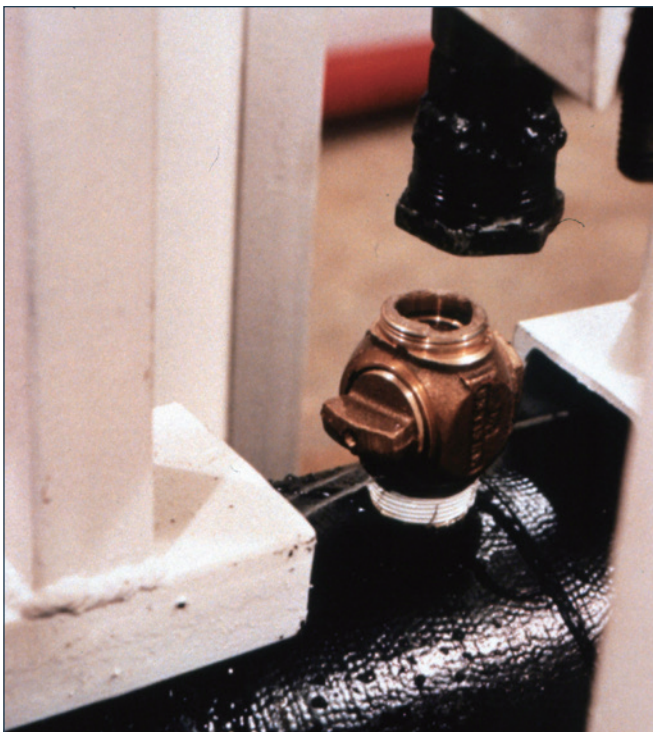
Six 3/4-inch direct taps were made on Ductile iron pipe specimens, which were initially torqued to 30 ft-lbs. Only one exhibited any leakage, which was observed at the threaded connection to the pipe at an internal pressure of 175 psi. This corporation stop was then retorqued for 40 ft-lbs to stop the leak. After retorque of this single corporation, **none of the connections exhibited any leaks, even at 500 psi, the pressure at which the tests were terminated.**

Retention of Corporation Stops

Another significant point of comparison is the vulnerability of damage to service connections. Figure 9 depicts the pull-out force and moment required to break off a 3/4-inch service tap in 6-inch Ductile iron pipe and PVC pipe, both in tension and as a cantilever.



The dramatic difference in values is even more significant because the failures of taps in the Ductile iron pipe tests were failures of the brass corporation stops. No damage was done to the pipe. In each case, failures of the taps in PVC pipe were failures of the pipe wall itself. This distinction is very important to the relative difficulty of repair. For more information, please see our tapping comparison brochure: [Tapping Ductile Iron Pipe vs. Polyvinyl Chloride Pipe](#)



Research shows that the strength of Ductile iron pipe walls exceeds the strength of the corporation stop, unlike PVC pipe walls. When stressed with either cantilever or pull-out loads, taps in Ductile iron pipe do not result in failure of the pipe walls. Photos of pull-out tests on PVC pipe show that leakage occurred at the threaded connection to the pipe, causing the pipe wall to break at the corporation stop. During the same tests, leakage occurred in the corporation stop plugs, as shown in the photo, and not at the threaded connection to the Ductile iron pipe. Failure occurred at the threaded connection for the service line, not the threaded connection to the pipe.

Use of Tapping Saddles

The integrity of direct tapping is questionable for all PVC thicknesses, but tapping saddles are required on AWWA C900 PVC pipe 18 inches and larger as well as certain classes of pipe less than 18 inches (UNI-PUB-08-21, p. 5).

On the other hand, the use of tapping saddles with Ductile iron pipe for normal residential services is unnecessary.

Tapping Advantages for Ductile Iron Pipe

When performing service taps on PVC pipe it is important to follow the guidelines laid out both in ANSI/AWWA C605 (“AWWA C605”) and the manufacturers’ installation guides.

A review of the direct tapping procedures outlined in AWWA C605 reveal the safety precautions that are recommended (AWWA C605, 2021, Sec. 8.4). For example:

- A reduction in pipeline pressure is suggested.
- Only direct tap DR 18 and DR 14 PVC pipe in sizes 6 inch through 16 inch.
- Only direct tap AWWA C900 PVC pipe. Do not direct tap molecularly oriented PVC pipe.
- Do not tap on the external bending radii of bent pipe.
- Do not create ovality or otherwise distort the pipe by over tightening the tapping machine or the saddle.
- Do not force the cutter through the pipe wall, make cuts slowly and use the follower very lightly.
- Do not tap within 2 feet of the spigot insertion line or the back of the bell or any restrained joint hardware for sizes 12 in. and smaller.
- Do not tap within 3 feet from the spigot insertion line or the back of the bell or any joint-restraint hardware.
- Multiple taps on a single pipe must be 18 inches apart and staggered, circumferentially.



The J-M installation guide provides explicit safety precautions for tapping PVC pipe under pressure. One of those precautions is to “prepare a means of simple and quick exit from the work area in the event of flooding. A sturdy ladder is recommended.” With PVC pipe failures such as these, such advice is worthwhile.

Tapping PVC pipe can be very dangerous due to the potential for PVC to catastrophically fail or rupture during tapping. According to JM Eagle, improper installation or misuse of tapping tools “may result in serious damage to pipe, property and/or people” (JM Eagle Installation Guide, 2019, p. 35).

The Uni-Bell tapping guide provides explicit safety precautions for tapping PVC pipe under pressure: “During the drilling or tapping of any pressurized pipe, basic safety precautions are advised to prevent personal injury to the workman in the event of sudden and unexpected pipe failure. They include:

- When a worker is drilling or tapping pipe under pressure, a second worker should be in the immediate vicinity.
- In addition to normal protective clothing, goggles or face shields should be worn.
- Ladders should be provided in the work area for quick exit.
- A protective blanket with a hole at its center to permit installation and operation of the tapping and drilling machine should be provided to cover the exposed area of the pipe.

The tapping crew should be familiar with the location of valves and their proper operation in case depressurization of the line is needed. Air should be removed from pipes before tapping. Failure to vent entrapped air can create a hazardous condition.”

Unlike Ductile iron pipe, which has been safely tapped numerous times in tapping contests, there are case histories of people being injured while tapping PVC pipe. This may be one reason the Uni-Bell PVC Pipe Association offers publications comprising more than 7,000 words of instruction on proper tapping procedures.

Service Tap Spacing

Due to PVC’s physical strength limitations, direct taps too close together can cause the pipe to split and fail. According to AWWA C605 “No direct tap shall be made closer than 2 ft. from the insertion line or the back of the bell or any joint-restraint hardware for nominal sizes 12 in. and smaller. For nominal sizes 14 in. and larger, no tap shall be made closer than 3 ft from the spigot insertion line or the back of the bell or any joint-restraint hardware. Multiple taps in a single pipe shall be staggered around the circumference and at least 18 in. apart when measured along the longitudinal axis of the pipe.”

With Ductile iron pipe there are no spacing or offset requirements for direct taps.

FLOW CONSIDERATIONS

Flow Tests

DIPRA performed flow tests on in-service piping in Blackwood, New Jersey; Dothan, Alabama; and Wister, Oklahoma to establish representative Hazen-Williams “C” factor values and compare overall flow characteristics of 12- and 18-inch Ductile iron pipe and PVC pipe (DIPRA Fall/Winter, 1986, pp. 8-9; DIPRA Spring/Summer, 1986, pp. 12-13; DIPRA, 1999, pp 16-18).

Although the PVC pipe has a slightly greater “C” factor value (indicating a slightly smoother internal pipe surface), for the same flow, head loss was less for Ductile iron pipe than for PVC because of Ductile iron pipe’s larger inside diameter. The results are shown in Figure 10.

In the 12-inch diameter Blackwood tests, the inside diameter of the cement-mortar-lined Ductile iron pipe was 5.8 percent larger than that of the PVC pipe, resulting in 12 percent more flow capacity. The calculated values for C were 131 and 138 for Ductile iron and PVC pipes, respectively.

In the 12-inch diameter Dothan tests, Ductile iron pipe’s inside diameter was 5.4 percent larger than that of the PVC specimen, an 11.1 percent larger capacity. PVC’s smaller inside diameter resulted in a higher velocity and a 23.5 percent higher head loss than the Ductile Iron Pipe although both pipe sections carried the same quantity of water. The calculated values for C were 137 and 140, for Ductile iron and PVC pipes, respectively.

In the 18-inch diameter Wister tests, the inside diameter of the cement-mortar lined Ductile iron

pipe was 8.5 percent greater than that of the PVC pipe, a 17.7 percent greater flow capacity. Although the PVC pipe had a slightly larger “C” factor value (141 versus 139), the PVC’s smaller inside diameter resulted in a constant 17.7 percent higher velocity to deliver the same quantity of water resulting in 44.9 percent higher head loss in PVC pipe than in Ductile iron pipe.

It might also be noted that the calculated values for C in PVC pipe (138, 137, and 141) were considerably less than the value for C of 150 that the PVC pipe industry recommends. The values calculated for Ductile iron pipe were much closer to the recommended value. The reason may have something to do with the fact that the value of C for PVC is based on laboratory tests rather than flow tests conducted on in-service pipelines, as was the case for Ductile iron pipe. Regardless, when normalized for flow rate, it is clear that the larger inside diameter of Ductile iron pipe governs headloss in the two pipe materials.

DIPRA has also performed several flow tests on the first cement-lined cast iron pipe, which was installed in Charleston, SC in 1922. The most recent of these flow tests was conducted in 2019 and found that the “C” factor value for the then 97-year-old cement lining was 140. This is impressive not only because this pipe was lined in the field in 1922 where one might expect a “rougher” surface than modern factory-applied linings, but because it demonstrates that the cement mortar lining maintains its high “C” factor value and doesn’t degrade overtime as incorrectly suggested by the PVC pipe industry. A video of the [2019 Charleston SC Flow Test](#) is also available at www.dipra.org.

FIGURE 10
Flow Test Results

Location	Year Installed	Year Tested	Pipe Size (in)	Flow Rate (gpm)	Pipe Material	Measured Inside Diam. (in)	C Factor	Velocity (f/s)	Headloss (f/1000f)
Blackwood, NJ	1975	1986	12	750	CML DI	12.20	131	2.0	1.2
	1976				PVC	11.53	138	2.3	1.5
Dothan, AL	1981	1986	12	750	CML DI	12.28	137	2.0	1.2
	1980				PVC	11.65	140	2.3	1.5
Wister, OK	1969	1999	18	1500	CML DI	18.53	139	1.8	0.6
	1998				PVC	17.08	141	2.1	0.8

Note how close the calculated values for C turned out to be. Note also that when the flow through these pipes are normalized, it is the actual inside diameter that is the determinant regarding head loss for each pipe. Higher head loss translates into more energy required to deliver a given flow; and more greenhouse gas emissions that result from the consumption of the additional.

Energy Savings

Ductile iron pipe's larger inside diameter results in significant energy savings, whether the savings are based on pumping costs or equivalent pipeline considerations ([DIPRA, 2016](#)). Because of Ductile iron pipe's larger than nominal inside diameter—and resulting lower pumping costs—utilities can save appreciably on power costs and continue to save money every year for the life of the pipeline.

As an alternative, by using equivalent pipeline theories, utilities can realize immediate savings with Ductile iron pipe. Because of Ductile iron pipe's lower head loss, PVC pipelines with equivalent head loss would require larger—thus, more expensive—pipe diameters over portions of the pipeline.

For example, a 30,000-foot-long, 24-inch Pressure Class 200⁵ (pressure rated at 300 psi) Ductile iron pipeline delivering 6,000 gallons per minute would have the same total head loss as 23,920 feet of 24-inch plus 6,080 feet of 30-inch Pressure Class 165 PVC pipe.

For more information, please see DIPRA's brochure "[Hydraulic Analysis](#)". Also see DIPRA's [["HYDRAULIC ANALYSIS AND GREENHOUSE GAS EMISSIONS"](#)] calculator.

⁵ Pressure rated at 300 psi; this is the minimum pressure class available for that diameter pipe.

OTHER CONSIDERATIONS

Pipe Handling

PVC pipe manufacturers claim that PVC pipe is easier to handle than Ductile iron pipe because it is lighter. But this ostensible advantage is greatly overrated. When pipe is delivered to a job site, it should always be checked while still on the truck for damage and to ensure that the load is securely fastened and can be unloaded in a safe manner.

AWWA standards and manuals for both PVC (AWWA C605, 2021) and Ductile iron pipe (AWWA C600, 2017) require proper equipment and methods for handling pipe and preclude rolling or dropping pipe into the trench. PVC is lighter than Ductile iron pipe; however, an 8-inch DR 14 PVC pipe weighs 230 pounds, not an insignificant weight for one person to handle. Twelve-inch DR 18 PVC weighs approximately 400 pounds. Even two men should not attempt to handle a load of this magnitude.

Each individual utility or contractor may have its own guidelines for what a safe load for one person is; however, 200 pounds exceeds the safe load for most workers. Thus, the same equipment is needed to dig the pipe trench and to safely unload and lower both Ductile iron pipe and PVC pipe into the trench.

Handling Damage

Compared to Ductile iron pipe, PVC is a very soft material and is consequently much more vulnerable to abrasions, scratches, and other damage during shipping and installation. According to JM Eagle “Severe impact could damage the pipe (particularly during cold weather)” (JM Eagle Installation Guide, 2019, p. 10). In fact, the C900-16 standard states that the “pipe surface shall be free from nicks and

scratches deeper than 10 percent of the wall thickness” (AWWA C900, 2016, Sec. 4.3).

Improper handling of PVC pipe can lead to impact damage, scratching, or gouging of the pipe wall. According to AWWA C605, “Any observed gouges or scratches that extend 10 percent or more into the pipe...shall justify rejection” (AWWA C605, 2021, Sec. 4.1.3).

On an 8-inch DR 18 PVC pipe, a 10 percent scratch (0.05-inch) is approximately the thickness of a dime! It is recommended that the inspector on a PVC pipe job be equipped with the proper gauge to measure such damage as might occur when the pipe is handled and installed.

Ductile iron pipe, on the other hand, is a tough material that is not usually scratched or gouged by the type of rough handling that can damage PVC pipe. Furthermore, the gouge resistance of pipe materials, along with tensile/compressive strengths, is becoming increasingly important with demanding new trenchless installation methods such as horizontal directional drilling (HDD) and pipe bursting. Because of Ductile iron pipe’s great strength and durability, there is no measurable loss of strength due to scratches and gouges from normal handling.

Water Hammer and Cyclic Loadings

Both Ductile iron pipe and PVC pipe are subjected to cyclic stresses from water hammer caused by velocity changes in the system. Ductile iron pipe has excellent resistance to such cyclic stresses.

Robert T. Hucks has reported, however, that the Hydrostatic Design Basis (i.e., the stress level resulting in failure in 11.4 years) of PVC is actually less under cyclic loading conditions than under static loading conditions (Hucks, R.T., 1972, p. 73).

In fact, Hucks proposed a cyclic hydrostatic design basis be used that would limit stress in the wall of PVC pipe to 1,000 psi. This reflected a factor of safety of 1.5 to 1 with respect to the fatigue limit of PVC pipe, which, Hucks noted, tests had shown to be 1,500 psi. The number of cycles until failure is also reduced by surface scratches on the pipe to a degree depending on their severity. According to Hucks, tests performed on plastic pipe have shown that a scratch 0.01 inch in depth and 10 inch in length on a 1 1/2 inch 160 psi pressure rated pipe reduced the cycles to failure from 52,000 to 9,600 (Hucks, R.T., 1972, p. 72). This critical depth is about 1/32 inch for 6-inch Class 150 PVC pipe. This property is not taken into consideration in the suggested PVC design procedures.

Bedding Requirements / Trenching Considerations

Due to the inherent weaknesses in PVC pipe, bedding conditions are much more critical than with Ductile iron pipe. Proper bedding is required to control deflection, which is the single criterion in design of PVC pipe for external loads. It is also important to control the stress that might be imparted to the pipe by the surrounding soil. Recommended installation practices for plastic piping provide that the pipe be surrounded by a soil with a minimum particle size so that the soil can be sufficiently compacted to develop uniform lateral passive soil forces in order to control lateral stress in the wall of PVC pipe. The soil also must be free of organic matter and the trench bottom must be smooth and free from large stones, large dirt clods, and any frozen materials, as these objects could cause localized stress and a reduction in strength due to scratches or abrasions.

Excavating for pressure piping should result in a smooth, flat-bottom trench. The designer in all cases assumes that an equal and uniform bedding condition is to be provided throughout the length of the pipeline. This reduces the potential for beam or point loads along the length of the pipe during installation. Bell holes are required in soils that are not soft enough to absorb the bell and still allow the uniform support along the barrel that is desired for any pipe material. If bell holes are not provided for PVC pipe, the pipe may be bent or point loadings may be applied that impart additional localized stresses to the pipe. Such stresses are the enemy of a long-life expectancy for PVC pipe.

The required type of trench and pipe embedment depends on a pipe's stiffness, strength, and ability to withstand trench loads. Most designers require compacted bedding and select backfill in and around weaker flexible conduits such as PVC. To ensure control of stress in the pipe wall, PVC pipe should be provided select fill and compaction.

Standards for both PVC and Ductile iron pipe include laying conditions for installation of their respective products. Interestingly, the diagrams shown in the installation standard for PVC pipe (AWWA C605, 2021, p. 9), greatly resemble those shown in the design standard for Ductile iron pipe (AWWA C150, p. 13).

Even the descriptions of these laying conditions are very similar. However, this first glance does not reveal the true differences in those laying conditions—differences that reflect the advantage of installing a stronger pipe material.

The most important aspect of a laying condition is found in the resulting “Modulus of Soil Reaction,” or E' , in the standards. An empirical value, E' is used to classify the level of support that sidefill soils will offer the pipe in sustaining an external load. The most supportive trench for PVC pipe (Type 5 from AWWA C605) assumes an E' value of as high as 4,000 psi. This is contrasted with an E' value for Ductile iron pipe, for the same basic trench (Type 5 from AWWA C150) of just 700 psi. Thus, in order to moderate stress in PVC pipe, it requires nearly three times the support from backfill as does Ductile iron pipe. The lower value reflects a lesser reliance by Ductile iron pipe on its backfill to help sustain a given external load. It also reflects a more practical acknowledgement of what can routinely be accomplished in construction. An E' of 4,000 psi cannot be accomplished throughout the pipe zone without careful installation and compaction of the granular and select backfill material. An E' of 700 psi can be effectively achieved with much less effort and expense.

Because of Ductile iron pipe's inherent strength, Type 1 (flat bottom, loose backfill) or Type 2 (flat bottom, lightly consolidated backfill) trench conditions in accordance with ANSI/AWWA C150/ A21.50 are adequate for the vast majority of applications.

Pipeline Installation: Over-Insertion, Over-Deflection and Bending PVC Pipe

The process of installing PVC pipe offers additional opportunities for adding stress at joints resulting from over-insertion of the spigot past the bell recess and from over-deflection of the joint and bending of the pipe to change directions. Existing underground utilities sometimes are found in unexpected locations, and other unforeseen obstructions are often encountered during construction. Field engineering then comes into play, and the

pipeline must be reoriented and rerouted to avoid the obstruction. This is typically done by deflecting the joints, bending the pipe, the use of fittings or a combination of these.

With PVC pipe it is very easy to over-insert the spigot into the bell side of the joint, creating excessive stress at the joint, leading to failures. Additional sources of added stress can occur from over-deflection of the joints to change direction and from bending the pipe, also to change direction. JM Eagle cautions to “AVOID OVER-STRESSING THE BELL AND TO PREVENT POSSIBLE BREAKAGE AND/OR LEAKS, THE MAXIMUM ANGULAR DEFLECTION IN THE JOINTS IS 1 DEGREE (emphasis in the original) (JM Eagle, 2019, p.15).”

With this severe limitation on joint deflections, on 12-inch and smaller pipe, PVC pipe manufacturers recommend bending the pipe itself to make field adjustments. JM Eagle states that, “The line may be assembled above ground, in a straight line then offset when laid in the trench, if necessary” (JM Eagle, 2019, p. 15). Bending PVC pipe increases the stress in the pipe wall which decreases the time to failure as PVC pipe's service life is inversely proportional to the applied stress.

To prevent failures due to bending PVC pipe, JM Eagle states that, “Mechanical means should not be employed to accomplish these radii. It is the intent that the workers should accomplish this manually in the trench.” JM Eagle further recommends “(t)o avoid deflecting the joints while achieving curvature, it is recommended that the joints be sufficiently braced or backfilled and compacted to keep them stationary. Abrupt changes in direction shall be accomplished with fittings” (JM Eagle, 2019, p. 15). To accomplish this during installation, it would be reasonable to provide full-time inspection to ensure that all of

the joints are sufficiently braced and there is no over- deflection or excessive stress at the joints when the pipe is bent.

Another PVC pipe manufacture, Diamond Plastics, also warns that, “joint flexibility is reduced when the spigot is inserted beyond the first insert reference mark...(a)n ‘over-assembled’ joint can be under substantial stress” (Diamond Plastics, 2020, p. 8).

The impact of over-stressing the joint, either through over-insertion or over-deflection, has also been documented in peer-reviewed papers. In research conducted by a manufacturer of PVC pipe on the impact of over-insertion and over-deflection of PVC pipe gasketed joints, a manufacturer of PVC pipe concluded: “Abusive installation methods of PVC pressure pipe...can reduce the life span of the systems resulting in premature failures. The life reduction is proportional to the severity of the over-insertion and over-deflection” (Youssef, Y., et al, 2008).

Tucson Water reported problems associated with bending PVC pipe to change direction (Winn, L.B., 2018):

- “PVC pipe failures in the bending mode require replacement of an entire length of (usually split) pipe.
- If pipe is bent or deflected, cost-effective repairs cannot be made easily because new sections and existing joints do not align.
- At least some excavated C900 pipe failures exhibit stain marks on deflected joints where water has leaked past seals.
- Service taps are being specified on the tension side of curved PVC pipe in the design phase, potentially leading to split pipe failures and higher maintenance costs.”

Over-insertion of PVC pipe during assembly is such an issue with PVC pipe that there are metallic products available, such as the EBAA IRON Mega-Stop®, that are designed to prevent the over-insertion of the PVC spigot (EBAA Iron, 2018). These devices work like the external restrained joints such that there is a ring installed on the spigot behind the manufacture’s insertion line that prevents the spigot end from being over-inserted into the bell. Like the restrained joints, these over insertion devices dig into the pipe wall, which can gouge or scratch the pipe resulting in stress concentrations and potential failures. With Ductile iron pipe over-insertion of joints is not a concern and there are no special devices required to prevent it.

With Ductile iron pipe, no joint stress is required to obtain sufficient deflection. Depending on pipe diameter, push-on joint Ductile iron pipe has a joint deflection of up to 5° and mechanical joint up to 8.3° (AWWA C600, 2017). Ductile iron pipe fitted with ball and socket joints has a maximum deflection of up to 15° per joint in sizes up to and including 24-inch pipe; in sizes 30 inch and larger, maximum deflection varies from 12 1/2° to 15° (DIPRA, 2001).

Restrained Joints

Because restrained joints are not readily adaptable to PVC pipe, only a limited number of joint-restraining means are available for use with that pipe. Moreover, because all PVC restrained-joint mechanisms rely on grooved or serrated edges that dig into the pipe, they can potentially cause surface scratches to the piping material. Over time, these gouges may exceed the 10 percent wall thickness warned against in AWWA C605.

These systems may also result in localized stress in the PVC material that can reduce the design life of the pipe. Remember that additional thicknesses for service and casting allowances are added to Ductile iron pipe design, but not for PVC—even though the tensile strength is less for PVC than for Ductile iron pipe. Therefore, many utilities require that thrust blocks, rather than restrained joints, be applied to any point in the PVC piping system where the direction or cross-sectional area of the waterway changes.

On the other hand, a wide variety of restrained joints are readily available for Ductile iron pipe, giving the designer greater flexibility in pipeline design and installation.

Locating Pipe

Because it is a non-metallic substance, sound does not travel well through PVC pipe walls; whereas Ductile iron pipe's metallic walls carry sound extremely well. This means that locating buried PVC pipe or locating leaks in PVC pipe cannot be accomplished using the most popular devices. While it is difficult to locate PVC pipe, it must be done to avoid damage when excavating nearby. When plastic pipe is known to exist in the right of way, additional time might be required to pothole excavations to locate the pipe. Ductile iron pipe, on the other hand, can be easily found using conventional pipe locators commonly used by most utilities.

Locating non-metallic pipe is difficult at best. Very often, tracer wires and excavation tapes are installed in an effort to reduce the difficulty of locating these pipes. When tracer wires are used, they should be tested after installation to be sure that they are electrically continuous from one access point to the next.

Typically, access points would be at valve boxes, hydrants, etc. If the wires are not tested, then it is not known whether the system is working when it is initially installed. As an alternative to an electrically continuous tracer wire, a heavy gauge wire that can be detected with conventional locating equipment, even when conductivity is lost, can be used.

Nearby Excavation

Existing PVC pipe is substantially more vulnerable than is Ductile iron pipe to puncture or damage during excavation and construction of nearby pipelines.

It is necessary for utilities to provide field locations of their existing facilities to others planning excavations in the vicinity. One-call systems have been established to help avoid damage to existing underground utilities. Thus, locating piping materials is an important part of the future operation and maintenance of a piping system. As noted above, locating Ductile iron pipe is easy and convenient with virtually all locating equipment available on the market.

Buoyancy

PVC pipe is buoyant—a concern when installing the pipe material in areas having a high-water table or when trench flooding is likely to occur. To prevent loss of completed pipe embedment through flotation of the PVC pipe, it must be anchored (AWWA C605, 2021, p. 11; p. 13). Flotation is generally not a concern with Ductile iron pipe.

Sun Exposure

Special precautions must be taken when PVC pipe is exposed to sunlight for an extended period of time, because “PVC pipe can incur

surface damage when subjected to long-term exposure to ultraviolet (UV) radiation from sunlight, an effect called ultraviolet degradation” (M23, 2020, p. 8). According to AWWA C605, if PVC pipe is stored where it may be exposed to direct sunlight, it may require protective covering “...with provision for air circulation to minimize heat accumulation” (AWWA C605, 2021, p.6). The JM Eagle installation guide states that, “when PVC pipe is stored outside and exposed to prolonged periods of sunlight, an obvious discoloration or UV degradation of pipe could occur” (JM Eagle, 2019, p.11).

Although the long-term effects on PVC pipe exposed to sunlight have not been clearly determined, changes in material properties obviously occur since warnings are given concerning impact strength.

Ductile iron pipe is not vulnerable to the effects of exposure to sunlight or weathering.

Permeation

There is also a problem where soils contaminated with hydrocarbons such as gasoline or other chemicals are encountered. Plastic pipe walls and gasket materials are susceptible to permeation that can damage the material and contaminate the water. In a study conducted by the Sanitary Engineering and Environmental Health Research Laboratory at the University of California at Berkeley (Holsen, T.M., et al, 1991, p. 56), PVC was reported to be involved in 15 percent of the permeation incidents found in a literature search in the United States. Other agencies have also investigated occurrences of this phenomenon (MDEQ, 2000). Interestingly, the University of California report also notes that, previously, PVC pipe had “been considered as relatively immune to permeation” (Holsen, T.M. et al, 1991, p. 56).

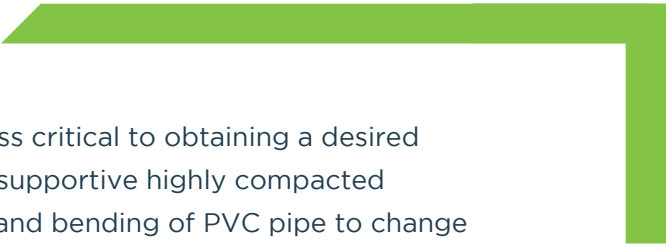
On the other hand, this same study reported only one incident where a gasket was permeated. In Ductile iron pipe, the only opportunity for permeation is at the gasket. The standard gasket used in push-on and mechanical joints is made from the elastomer styrene butadiene (“SBR”). Even though the University of California report cites just one occurrence of a permeated gasket, should contaminated soils be encountered in design, gaskets made of permeation-resistant materials such as Nitrile or fluorocarbon may be specified. In other words, while PVC pipe cannot be made to be resistant to soils containing permeants, Ductile iron pipelines can.

Another Environmental Factor

As a final observation regarding environmental considerations, it should be noted that PVC is made from petroleum derivatives, chlorine gas, and vinyl chloride, the latter two substances being of concern in environmental circles, while Ductile iron pipe is manufactured using recycled scrap iron and steel. In fact, the raw material used as the source for the iron in Ductile iron pipe made in the United States has been documented to comprise a minimum average recycled content of 90% recycled scrap iron and steel.

Performance History

The performance of Ductile iron pipe extends over 50 years, and because of its close physical resemblance to gray cast iron pipe, the long-term record of cast iron can be used to predict the life of a Ductile iron pipeline (DIPRA CIPCC, 2021). This comparison has been enhanced by extensive research on the comparative corrosion rates between ductile iron and gray cast iron, which has shown ductile iron to be at least as corrosion resistant as gray cast iron (Bonds, R.W., et al, 2005, pp. 93-95) (Sears, E.C., 1968).



Conclusion

The weaknesses in PVC pipe make controlling stress critical to obtaining a desired service life. Control of stress involves providing a supportive highly compacted select backfill, avoiding the use of joint deflection and bending of PVC pipe to change directions and adding after-market devices to avoid over-insertion of the spigot into and beyond the bell. Complete specifications include the addition of tracer wires to help locate the pipe when excavating nearby. This places additional importance on PVC pipeline installation, to the point that it is prudent to provide full-time inspection by trained personnel.

This brochure has presented major considerations facing design engineers when deciding what type of piping material to specify for any given application. Evidence has been presented proving not all pipe materials are equal. In every test of strength, durability, and dependability from cyclic loading and joint deflection to energy savings and tapping, Ductile iron pipe proves superior to PVC pipe. The exorbitant costs associated with early replacement of underground piping make the engineer's initial choice of the best available piping material the most economical decision over the long term. Ductile iron pipe is a proven performer—a product with a performance history dating back more than 60 years—several centuries if its predecessor Cast iron pipe is considered. Design engineers and owners have traditionally considered Ductile iron pipe the highest-quality piping material available. In this brochure, we've pointed out the many reasons why Ductile iron pipe will always be the right decision.

References

- ASTM D2837, 2022, “Standard Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials,” American Society for Testing and Materials, West Conshohocken, PA.
- ASTM E23, 2018, “Standard Test Method for Notched Bar Impact Testing of Metallic Materials,” American Society for Testing and Materials, West Conshohocken, PA.
- AWWA C150, 2014, “ANSI/AWWA C150/A21.50: Thickness Design of Ductile-Iron Pipe,” American Water Works Association, Denver, CO.
- AWWA C600, 2017, “ANSI/AWWA C600: Installation of Ductile Iron Mains and Their Appurtenances,” American Water Works Association, Denver, CO.
- AWWA C605, 2021, “ANSI/AWWA C605-21: Underground Installation of Polyvinyl Chloride (PVC) and Molecularly Oriented Polyvinyl Chloride (PVCO) Pressure Pipe and Fittings,” American Water Works Association, Denver, CO.
- AWWA C900, 1975, “ANSI/AWWA C900-75: Polyvinyl Chloride (PVC) Pressure Pipe, 4-inch Through 12-inch, for Water” American Water Works Association, Denver, CO.
- AWWA C900, 1997, “ANSI/AWWA C900-97: Polyvinyl Chloride (PVC) Pressure Pipe and Fabricated Fittings, 4 In. Through 60 In.,” American Water Works Association, Denver, CO.
- AWWA C900, 2007, “ANSI/AWWA C900-07: Polyvinyl Chloride (PVC) Pressure Pipe and Fabricated Fittings, 4 In. Through 12 In., for Water Transmission and Distribution,” American Water Works Association, Denver, CO.
- AWWA C900, 2016, “ANSI/AWWA C900-16: Polyvinyl Chloride (PVC) Pressure Pipe and Fabricated Fittings, 4-inch Through 60-inch,” American Water Works Association, Denver, CO.
- AWWA C905, 1988, “ANSI/AWWA C905-88 Standard for Polyvinyl Chloride (PVC) Water Transmission Pipe, Nominal Diameters 14 in. Through 36 in.,” American Water Works Association, Denver, CO.
- AWWA C150, 2014, “ANSI/AWWA C150/A21.50, Standard Thickness Design for Ductile-Iron Pipe.
- Bonds, R.W., et al, 2005, “Corrosion and corrosion control of iron pipe: 75 years of research,” Journal of the American Water Works Association, June 2005, American Water Works Association, Denver, CO.
- Diamond Plastics, 2020, *Recommendations for Installation of AWWA C900 4” thru 60”*, Diamond Plastics Corporation, Grand Island, NE.
- DIPRA, 1987, “Direct Tapping Comparison: Ductile Iron Pipe Versus Polyvinyl Chloride Pipe,” *Ductile Iron Pipe News – Fall/Winter 1987*, Ductile Iron Pipe Research Association, Birmingham, AL.
- DIPRA, 1999, “Flow Tests Confirm the Superiority of Ductile Iron Pipe vs PVC,” *Ductile Iron Pipe News – Fall/Winter 1999*, Ductile Iron Pipe Research Association, Birmingham, AL.

- DIPRA, 2001, "Ductile Iron Pipe for Subaqueous Crossings," Ductile Iron Pipe Research Association, Birmingham, AL.
- DIPRA, 2016, "Hydraulic Analysis of Ductile Iron Pipe," Ductile Iron Pipe Research Association, Birmingham, AL.
- DIPRA CIPCC, 2021, "Cast Iron Pipe Century Club and Sesquicentennial Club," Ductile Iron Pipe Research Association, Birmingham, AL.
- DIPRA Fall/Winter, 1986, "Blackwood Flow Tests Prove Ductile Iron Pipe's Lower Head Loss," *Ductile Iron Pipe News – Fall/Winter 1986*, Ductile Iron Pipe Research Association, Birmingham, AL.
- DIPRA Spring/Summer, 1986, "Flow Tests Show Lower Head Loss for Ductile Iron Pipe," *Ductile Iron Pipe News – Spring/Summer 1986*, Ductile Iron Pipe Research Association, Birmingham, AL.
- EBAA Iron, 2018, "MEGA-STOP Series 5000 Bell Protection System," EBAA Iron, Eastland, TX, <https://ebaa.com/files/pdf/brochures/Brochure.5000.pdf>.
- Holsen, T.M., et al, 1991, "Contamination of Potable Water by Permeation of Plastic Pipe," Journal of the American Water Works Association, August 1991, American Water Works Association, Denver, CO.
- JM Eagle, 2019, "Blue Brute/Big Blue/Ultra Blue AWWA C900/C905/C909 ASTM F 1483 Installation Guide," J-M Manufacturing Co., Inc., Livingston, NJ.
- JM Eagle, 2022, "What is the difference between pressure class and pressure rating?," <http://jmeagle.com/what-difference-between-pressure-class-and-pressure-rating>. Accessed April 26, 2022.
- M23, 2020, "Manual of Water Supply Practices M23 - PVC Pipe – Design and Installation," American Water Works Association, Denver, CO.
- MDEQ, 2000, "Some Town Water Supplies Threatened," News Release – Montana Department of Environmental Quality, March 17, 2000.
- Pacific Plastics, Inc., 2017, "What is the difference between pressure class and pressure rating?," <https://www.pacificplasticsinc.com/faq>. Accessed April 26, 2022.
- Sears, E.C., 1968, "Comparison of the Soil Corrosion Resistance of Ductile Iron pipe and Gray Cast Iron Pipe," Materials Protection, October 1986.
- Uni-Bell, 2012, "Handbook of PVC Pipe Design and Construction," Uni-Bell PVC Pipe Association, Dallas, TX.
- UNI-PUB-08-21, "PVC Pressure Pipe Tapping Guide," Uni-Bell PVC Pipe Association, Dallas, TX.
- Winn, L.B., 2019, "Limits of Longitudinal Bending of C900 PVC Pipe," Journal of the American Water Works Association, January 2018.
- WRF 4680, 2016, "State of the Science: Plastic Pipe," Water Research Foundation, Denver, CO.
- Youssef, Y., Gauthier, S., and St-Aubin, R., 2008, *Effect of over-insertion and over-deflection on the integrity of PVC pressure pipe – Numerical and experimental analysis*, ASCE Pipelines Conference 2008.

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

Ductile Iron Pipe Research Association

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