Ductile-Iron Pipe and Fittings

MANUAL OF WATER SUPPLY PRACTICES

M41



Third Edition

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Preface

This is the third edition of AWWA M41, *Ductile-Iron Pipe and Fittings*. This manual provides the user with both technical and general information to aid in the design, specification, procurement, installation, and understanding of ductile-iron pipe and fittings. It is a discussion of recommended practice, not an AWWA standard calling for compliance with certain specifications. It is intended for use by utilities and municipalities of all sizes, whether as a reference book or textbook for those not fully familiar with ductile-iron pipe and fitting products. Design engineers and consultants may use this manual in preparing plans and specifications for new ductile-iron pipe projects.

The manual covers ductile-iron pipe and fitting products and certain appurtenances and their application to practical installations, whether of a standard or special nature. For adequate knowledge of these products, the entire manual should be studied. Readers will also find the manual a useful source of information when assistance is needed with specific or unusual conditions. The manual contains a list of applicable national standards, which may be purchased from the respective standards organizations (e.g., AWWA, ASTM). Standards referenced in this manual refer to the latest editions.

Credit is extended to the Ductile Iron Pipe Research Association (DIPRA) for granting permission to reprint numerous graphics and tables found throughout this manual.

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Chapter 1

General Information and History

This manual provides the user with both technical and general information to aid in the design, specification, procurement, installation, and understanding of ductile-iron pipe.

The manual describes ductile-iron pipe and fitting products, appurtenances, and their application to practical installations, whether of a standard or special nature.

1.1 HISTORY

1.1.1 General

The history of pipe parallels that of civilization. The earliest communities were established near water sources that later became inadequate as populations increased. Hydraulic engineering was born of the necessity to transport water closer to the point of use. From ancient Babylon's clay pipes, to the underground tunnels of ancient Greece, to the aqueducts of the Roman Empire, to the cast-iron mains of Versailles, France, to today's modern pipe, the search for an affordable piping material with reliable strength and durability evolved. Cast-iron pipe rapidly became the standard material for water distribution mains. Today, in the United States and Canada alone, there are more than 622 utilities that have had cast-iron distribution mains with continuous service records of more than 100 years, and 23 for 150 years or more.

The production of iron pipe most likely developed from or coincided with the manufacture of cannons as early as the year 1313. There is an official record of cast-iron pipe being manufactured at Siegerland, Germany, in 1455 for installation at the Dillenberg Castle.

In 1664, King Louis XIV of France ordered the construction of a cast-iron pipe main to extend 15 mi (24 km) from a pumping station at Marly-on-Seine to Versailles to supply water for the fountains and town. This cast-iron pipe provided continuous service for more than 330 years. When the line was originated, the production of iron required the use of expensive charcoal for the reduction of the iron ore. By 1738, success

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had been achieved in producing lower-cost iron by using coke instead of charcoal. Following this success, the more progressive cities began to install cast-iron mains.

The use of cast-iron pipe was introduced in the United States in the early 1800s. Since that time, various other piping materials have been offered for water distribution. However, waterworks engineers continued to use cast iron until ductile iron, a stronger and equally durable piping material, became available.

1.1.2 Development of Joints

Flanged. Originally, cast-iron pipe was made with flanged joints, using lead gaskets. Improved joints of this type are still used for many aboveground plant installations and other specialized applications.

Bell and spigot. The bell and spigot joint was developed in 1785 and was used extensively until the 1950s. This joint was assembled by caulking yarn or braided hemp into the base of the annular bell cavity and then pouring molten lead into the remaining space inside the bell. On solidification, the lead was compacted by caulking, thus effecting a watertight seal. Materials other than lead have also been used to confine yarn or hemp in the base of the bell cavity.

Mechanical joint. The mechanical joint was developed for gas industry use in the late 1920s but has since been used extensively in the water industry. This joint has standardized dimensions and uses the basic principle of the stuffing box and gland, with a rubber gasket being compressed by the gland.

Roll-on joint. The roll-on joint was developed in 1937 and was used for approximately 20 years before its manufacture was discontinued. Assembly of this joint involved a compressed rubber gasket rolled under a restriction ring, followed by caulked square braided jute. The remainder of the joint was packed with a bituminous compound.

Push-on joint. The push-on joint was developed in 1956 and represented an important advancement in the water distribution field. This joint consists of a single rubber gasket placed in a groove inside the socket at the bell end of the pipe. After lubricating the joint in accordance with the manufacturer's instructions, the plain end of the pipe is pushed past the gasket, compressing it and forming a seal that is tight versus high internal pressures, vacuum, and external water head. Assembly of the push-on joint is simple and fast. Large bell holes are not required for this joint, and it can be assembled under wet-trench conditions or even under water.

Special joints. Several special joints are available. These joints include ball and socket for subaqueous crossings, plain-end coupled, threaded and coupled, and other variations of restrained joints.

A more detailed description of the joints used with ductile-iron pipe is found in chapter 5 of this manual.

1.1.3 Development of Ductile-Iron Pipe

The advent of ductile-iron pipe in 1948 was one of the most significant developments in the pressure pipe industry. Quickly recognized as a pipe material with all the good qualities of gray cast-iron pipe plus additional strength and ductility, it was first used for special and severe conditions of high pressure, water hammer, and excessive external loads. For more than 50 years, it has proved to be virtually trouble and maintenance free as an underground pressure pipe material, and today it is used in the transportation of raw and potable water, sewage, slurries, and process chemicals. The strength and rugged durability of ductile iron results in a high level of operational reliability. For these reasons, it rapidly replaced gray cast iron in the marketplace and is the iron piping material now specified by waterworks professionals.

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1.1.4 Manufacture of Ductile-Iron Pipe

The centrifugal casting methods used in manufacturing ductile-iron pipe have been in the process of commercial development and refinement since 1925. The steady improvements that led to the present state of the art have been covered by hundreds of patents and technical papers, and represent the ingenuity of many dedicated engineers, metallurgists, and foundry personnel. A detailed description of the metallurgical and physical characteristics of ductile-iron pipe and fittings produced to ANSI*/AWWA standards is in chapter 3 of this manual.

1.2 APPLICATIONS AND APPURTENANCES

Ductile-iron pipe and related products convey water from its source to its point of use through the myriad stages of storage, transmission (Figure 1-1), filtration, pumping, chemical treatment, and distribution. After the water is used, ductile-iron pipe plays a similar part in collecting, conveying, pumping, treating, reusing, and discharging wastewater in the never-ending water cycle. Ductile-iron pipe has long been noted for its long-term economy, performance, reliability, and proven record in serving the public's health, safety, and daily water needs.

1.2.1 Applications

Ductile-iron pipe that meets the requirements of various pertinent AWWA standards is used for numerous applications, some of which are

- Raw water supply lines
- Transmission mains
- Distribution mains
- Fire mains
- Sewer force mains
- Subaqueous crossings
- Air service
- Pump station piping
- Intake lines
- Brine handling
- Acid handling
- Sulfur handling
- Gravity sewers
- Treatment plant piping
- Outfall mains
- Reclaimed water lines
- Penstocks

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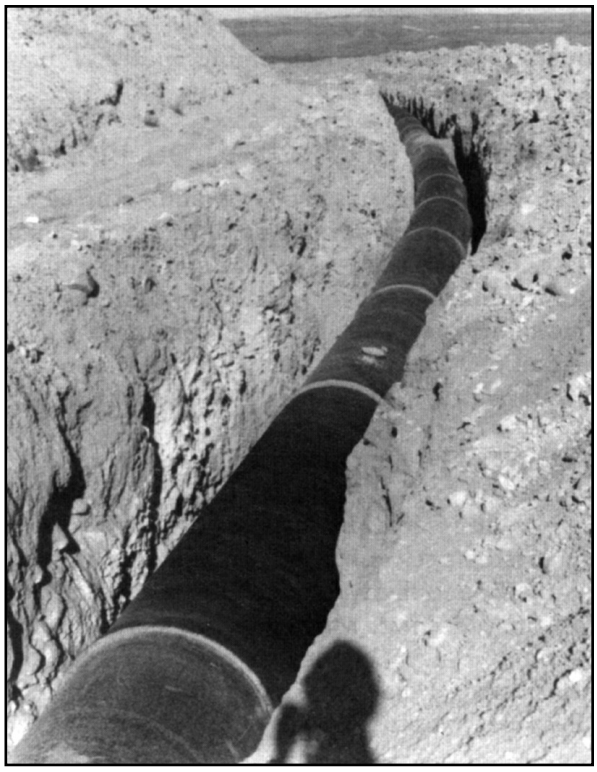


Figure 1-1 A 48-in. ductile-iron pipe water transmission main

- Various chemical processes piping
- Lift station piping
- Geothermal and hydronic piping
- Culverts

Various papers and reports have been published concerning unusual installations, such as applications subject to buoyancy, low pressures, or partial vacuum, etc., as well as routine applications of ductile-iron pipe. Data on many of these applications are available from engineering handbooks, journals, manufacturers' catalogs, and the Ductile Iron Pipe Research Association (DIPRA).*

1.2.2 Appurtenances

Ductile-iron piping systems have great versatility when combined with the diversity of fittings, joints, valves, hydrants, coatings, linings, gaskets, and specials available today. More than 15,000 variations of fitting patterns are currently available. Almost all of these fittings are manufactured under various ANSI/AWWA standards that ensure quality, performance, and standardization. ANSI/AWWA standards also provide requirements for a variety of joints, gaskets, linings, and corrosion control systems for virtually any water system application.

Valves to control flow, direct flow, shut off, vent, prevent backflow, and provide fire

* Ductile Iron Pipe Research Association, 245 Riverchase Parkway East, Suite O, Birmingham, AL 35244.

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protection are available in joints and types compatible with ductile-iron pipe systems. These valves and hydrants are manufactured according to ANSI/AWWA standards, as well as various insurance and independent test laboratory requirements in some cases.

Many special applications can be provided in ductile-iron pipe systems, such as restrained joints, flexible joint subaqueous pipe, base-mounted fittings, bonded joints, self-locking gaskets, epoxy or other special linings, and polyethylene encasement.

1.3 DUCTILE IRON PIPE RESEARCH ASSOCIATION (DIPRA)

DIPRA, formerly the Cast Iron Pipe Research Association or CIPRA, is a nonprofit organization whose members are manufacturers of ductile-iron pressure pipe. Since 1915, the association has provided engineering and research information on cast- and ductile-iron products by

- Participating in national and international standards development by ANSI, AWWA, ASTM International*, American Society of Mechanical Engineers (ASME),† NACE International (NACE),‡ National Fire Protection Association (NFPA),§ and the International Organization for Standardization (ISO)**
- Presenting engineering seminars on design, pipeline construction, corrosion control, and special applications and problems
- Providing field services, such as soil investigations, flow tests, and consultation with engineers on piping problems, including pipe and system design
- Publishing research and engineering information in technical papers, brochures, and manuals

* ASTM International, 100 Barr Harbor Dr., West Conshohocken, PA 19428-2959.

† American Society of Mechanical Engineers, 345 E. 47th St., New York, NY 10017.

‡ NACE International, 1440 South Creek Dr., Houston, TX 77084-4906.

§ National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02269-9101.

** ISO standards are available through ANSI, 25 W. 43rd St., Fourth Floor, New York, NY 10036-7406.

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Chapter 2

Applicable Standards

AWWA standards for cast-iron pipe date back to 1890. Today, AWWA publishes 11 standards related to ductile-iron pipe, ductile- and gray-iron fittings, and related items, including joint materials, design, and installation. These standards are individually revised, updated, and published on a five-year basis. Other organizations that publish standards related to ductile-iron pipe and fittings include ASTM* and the International Organization for Standardization (ISO).†

2.1 RELATED STANDARDS

The following describes the current editions of standards related to ductile-iron pipe and fittings.

2.1.1 ANSI/AWWA C104/A21.4,[1] Standard for Cement–Mortar Lining for Ductile-Iron Pipe and Fittings

First used in 1922 in Charleston, S.C., cement–mortar lining has proved to be a very effective means of preventing tuberculation and maintaining a high flow coefficient in both gray- and ductile-iron pipe and fittings. As a result, ductile-iron pipe as well as gray- and ductile-iron fittings used for potable water applications are normally furnished with a cement–mortar lining unless otherwise specified by the purchaser.

2.1.2 ANSI/AWWA C105/A21.5,[2] Standard for Polyethylene Encasement for Ductile-Iron Pipe Systems

Loose polyethylene encasement was first used experimentally in the United States in 1951 to protect cast-iron pipe in corrosive environments. The first field installation of polyethylene encasement of cast-iron pipe in an operating water system was completed in 1958. Since that time, thousands of installations have been made in severely

* ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

† ISO standards are available through the American National Standards Institute, 25 W. 43rd St., Fourth Floor, New York, NY 10036-7406.

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corrosive soils throughout the United States in pipe sizes ranging from 3 in. to 64 in. (76 mm to 1,600 mm) in diameter. This history of usage, coupled with extensive and ongoing research, has clearly demonstrated the efficacy of polyethylene encasement as a corrosion protection means for both gray- and ductile-iron pipe. Polyethylene encasement is also used as a soil corrosion preventive in a number of other countries, and an International Standard for Polyethylene Sleeving (ISO-8180)[3] was adopted after the procedure was developed in the United States. There is also an ASTM A674[4] covering polyethylene encasement for ductile-iron pipe, which closely parallels the ANSI/AWWA standard.

The ANSI/AWWA standard describes material requirements, effects of sunlight, tube size or sheet width, and installation methods. Appendix A to the standard describes a method for evaluating potentially corrosive environments to gray- and ductile-iron pipe to determine when polyethylene encasement should be used.

2.1.3 ANSI/AWWA C110/A21.10,[5] Standard for Ductile-Iron and Gray-Iron Fittings

This standard describes requirements and dimensions of ductile-iron and gray-iron fittings in mechanical, flanged, and push-on joint configurations. The standard further describes markings, certification requirements, inspection, coatings and linings, and acceptance tests. Detailed tables include data on thickness requirements, joint dimensions, gasket seats, and laying lengths.

2.1.4 ANSI/AWWA C111/A21.11,[6] Standard for Rubber-Gasket Joints for Ductile-Iron Pressure Pipe and Fittings

This standard describes rubber-gasketed joints for gray- and ductile-iron pipe and fittings with mechanical joints, push-on joints, or modified mechanical or push-on joints. The standard includes detailed requirements for each joint type, such as dimensions, tolerances, lubrication, gaskets, marking, and packing. Also described in the standard are requirements for glands, gaskets, and bolts, along with tables designating tolerances, dimensions, physical specifications, thread length and depth, bolt sizes, and torque ranges. Notes on installing mechanical joints, including recommended bolt torques to be applied, are in the appendix of the standard.

2.1.5 ANSI/AWWA C115/A21.15,[7] Standard for Flanged Ductile-Iron Pipe With Ductile-Iron or Gray-Iron Threaded Flanges

This standard pertains to flanged ductile-iron pipe with either gray- or ductile-iron threaded flanges. Tables are provided that describe required thickness, working pressure, class of pipe, and weights and dimensions. The standard describes inspection and certification by the manufacturer, acceptance on delivery, flanges to be used, fabrication procedures, coatings, linings, and markings. A table of flange gasket dimensions is also included in the appendix.

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2.1.6 ANSI/AWWA C116/A21.16,[8] Standard for Protective Fusion-Bonded Epoxy Coatings for the Interior and Exterior Surfaces of Ductile-Iron and Gray-Iron Fittings

This standard describes protective fusion-bonded epoxy coatings for the interior and exterior surfaces of ductile-iron and gray-iron fittings used for water, wastewater, and reclaimed water systems. The standard describes the material, application, and performance requirements for these coatings. It does not describe coatings agreed on between the purchaser and the manufacturer for special service conditions, such as salt water, sewers, acid, high temperature, and so forth.

2.1.7 ANSI/AWWA C150/A21.50,[9] Standard for Thickness Design of Ductile-Iron Pipe

The thickness design of ductile-iron pipe is presented in this standard, along with an example problem that illustrates proper application of the design method. Tables and charts are also provided that describe earth loads, truck loads, trench loads, design values for standard laying conditions, casting tolerances, diameter–thickness ratios, and other pertinent design parameters.

2.1.8 ANSI/AWWA C151/A21.51,[10] Standard for Ductile-Iron Pipe, Centrifugally Cast

This standard describes the manufacture of ductile-iron pipe for water, wastewater, and reclaimed water systems with push-on joints and mechanical joints. It includes general requirements, inspection and certification by the manufacturer, inspection-delivery-acceptance by the purchaser, tolerances or permitted variations, coatings and linings, testing requirements, marking and weighing of pipe, foundry records required, defective specimens and retests, and pipe rejection criteria. Tables are provided for standard thickness requirements, rated working pressure, maximum depth of cover, and standard dimensions and weights of push-on joint and mechanical joint ductile-iron pipe. Appendix A of this standard consists of two tables that show pipe thicknesses required for various tap sizes.

2.1.9 ANSI/AWWA C153/A21.53,[11] Standard for Ductile-Iron Compact Fittings for Water Service

A recent development in the industry is the introduction of compact fittings designed to use the attendant strength of ductile iron. Compact fittings are alternatives to those covered by ANSI/AWWA C110/A21.10.

This standard describes compact ductile-iron fittings ranging in size from 3 in. through 48 in. (76 mm through 1,219 mm), with mechanical joints, push-on joints, or such other joints (except flanged joints) as specified, and 54 in. through 64 in. (1,400 mm through 1,600 mm) with push-on or flanged joints. The information provided closely parallels that given in ANSI/AWWA C110/A21.10.

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2.1.10 ANSI/AWWA C600,[12] Standard for Installation of Ductile-Iron Water Mains and Their Appurtenances

This standard pertains to the installation of ductile-iron water mains and their appurtenances, and describes such topics as inspection, handling, storage, pipe installation, joint assembly, backfilling, hydrant installation, thrust restraint, flushing, pressure and leakage tests, highway and railroad crossings, and tapping. Many tables and diagrams are provided for clarification.

2.1.11 ANSI/AWWA C606,[13] Standard for Grooved and Shouldered Joints

This standard, describing grooved and shouldered joints, includes sections on general requirements, materials, general design, inspection, testing, and rejection. Tables and illustrations provide grooving dimensions, coupling and joint configurations, and other pertinent information.

2.2 OTHER REFERENCE STANDARDS AND SPECIAL PRODUCTS

In addition to the ANSI/AWWA standards described previously, the following standards are commonly used by the industry:

- ASTM A377[14]—Standard Index of Specifications for Ductile Iron Pressure Pipe
- ASTM A674—Standard Practice for Polyethylene Encasement for Ductile Iron Piping for Water or Other Liquids
- ASTM A716[15]—Standard Specification for Ductile Iron Culvert Pipe
- ASTM A746[16]—Standard Specification for Ductile Iron Gravity Sewer Pipe

Because of innovations in research, design, and manufacturing methods, and in response to changing needs of the marketplace, manufacturers of ductile-iron pipe and related products also offer other products that are not currently included in ANSI/AWWA standards. These products include restrained joints, bell-less joints, special linings and coatings, special fittings, and welded-on bosses and outlets. Many of these products meet applicable parts of current standards, and some may be included in future revisions. Information on some of these products is included in this manual. For more details, consult the manufacturers.

REFERENCES

1. Standard for Cement–Mortar Lining for Ductile-Iron Pipe and Fittings. ANSI/AWWA Standard C104/A21.4. Denver, Colo.: American Water Works Association.
2. Standard for Polyethylene Encasement for Ductile-Iron Pipe Systems. ANSI/AWWA Standard C105/A21.5. Denver, Colo.: American Water Works Association.
3. International Standard for Polyethylene Sleeving. ISO-8180. Geneva, Switzerland.
4. Standard Practice for Polyethylene Encasement for Ductile Iron Piping for Water or Other Liquids. ASTM A674. West Conshohocken, Pa.: ASTM International.
5. Standard for Ductile-Iron and Gray-Iron Fittings. ANSI/AWWA C110/A21.10. Denver, Colo.: American Water Works Association.
6. Standard for Rubber-Gasket Joints for Ductile-Iron Pressure Pipe and Fittings. ANSI/AWWA C111/A21.11. Denver, Colo.: American Water Works Association.

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7. Standard for Flanged Ductile-Iron Pipe with Ductile-Iron or Gray Iron Threaded Flanges. ANSI/AWWA C115/A21.15. Denver, Colo.: American Water Works Association.
8. Standard for Protective Fusion-Bonded Epoxy Coatings for the Interior and Exterior Surfaces of Ductile-Iron and Gray-Iron Fittings. ANSI/AWWA C116-A21.16. Denver, Colo.: American Water Works Association.
9. Standard for Thickness Design of Ductile-Iron Pipe. ANSI/AWWA C150/A21.50. Denver, Colo.: American Water Works Association.
10. Standard for Ductile-Iron Pipe, Centrifugally Cast. ANSI/AWWA C151/A21.51. Denver, Colo.: American Water Works Association.
11. Standard for Ductile-Iron Compact Fittings for Water Service. ANSI/AWWA C153/A21.53. Denver, Colo.: American Water Works Association.
12. Standard for Installation of Ductile-Iron Water Mains and Their Appurtenances. ANSI/AWWA C600. Denver, Colo.: American Water Works Association.
13. Standard for Grooved and Shouldered Joints. ANSI/AWWA C606. Denver, Colo.: American Water Works Association.
14. Standard Index of Specifications for Ductile Iron Pressure Pipe. ASTM A377. West Conshohocken, Pa.: ASTM International.
15. Standard Specification for Ductile Iron Culvert Pipe. ASTM A716. West Conshohocken, Pa.: ASTM International.
16. Standard Specification for Ductile Iron Gravity Sewer Pipe. ASTM A746. West Conshohocken, Pa.: ASTM International.

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Chapter 3

Manufacturing and Testing

3.1 MANUFACTURING

The process of manufacturing ductile-iron pipe and fittings begins in a pipe mill with the controlled melting of steel scrap, iron scrap, plant-returned scrap, and, in some operations, pig iron. Because of the high volumes of iron required for efficient production, melting in most pipe and fittings foundries is performed in cupolas or various types of electric furnaces. The resulting molten iron must be desulfurized so that later treatment will produce the nodular or spheroidal graphite form that is characteristic of the ductile-iron microstructure. Desulfurization can be accomplished in several ways. In pipe making, it is usually done by mixing calcium carbide or lime and fluorspar into the melt. The mixing mechanism can be a ceramic stirring beam (Rheinstahl process) or the introduction of inert gas into the bottom of a ladle through a porous plug.

3.1.1 Metallurgical Terms

Several metallurgical terms have been used in this chapter with which the reader may not be familiar. These terms are defined as follows:

Ductile iron: A cast ferrous material in which a major part of the carbon content occurs as free graphite in a substantially nodular or spheroidal form.

Austenitizing: A heat treatment that heats iron-base alloys to a temperature at which the carbon will go into solution, thus dissolving iron carbides. (The high-temperature phase of iron is called austenite.)

Carbide (iron): A hard compound of iron and carbon (Fe_3C), also called cementite.

Ferrite: Mostly pure iron.

Ferritizing: Heat treatment to convert iron-base alloys to ferrite.

Pearlite: A constituent of ductile iron, gray iron, and steel the microstructure of which is composed of alternate layers of ferrite and iron carbide.

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3.1.2 Magnesium Treatment

To produce ductile iron's spheroidal graphite microstructure, the desulfurized iron must be further treated with magnesium. In pipe making, the magnesium is usually introduced either in pure form or by adding a magnesium-bearing ferrosilicon alloy in lump form. In the latter form, sometimes as much as half of the required magnesium will be replaced by rare earth metals that tend to mitigate the effects of deleterious "tramp" elements and/or reduce the flare and fume associated with the treatment.

The proper quantity of magnesium to be used is sensitive and critical. Insufficient magnesium will result in degenerated graphite nodules, and excess magnesium, in addition to being uneconomical, can lead to excess carbide formation and dross inclusions. Therefore, because the amount of magnesium necessary is proportional to the sulfur content, frequent and accurate sulfur analyses are necessary to maintain adequate control of the magnesium additions and the quality of the finished product.

Properly treated iron will solidify with the graphite in the form of nodules or spheroids. However, because magnesium has a low vaporization temperature and low solubility in iron, the treated metal must be cast relatively soon after magnesium addition for retention of its ductile characteristics. The distribution and shape of the graphite nodules are set when the metal solidifies in the mold and will remain essentially unchanged during subsequent processing.

3.1.3 Casting

The matrix (primary internal structure) of pipe centrifugally cast in water-cooled metal molds will contain various proportions of structures known as ferrite (relatively high ductility), pearlite (reduced ductility and toughness), and iron carbide (hard). Pipe centrifugally cast in other types of molds might contain proportions of ferrite and pearlite but, because of slower cooling, can be produced without containing carbide. The structures obtained depend on the variations in iron chemistry, pouring temperature, solidification rate, and inoculation at the casting machines.

The essential elements of pipe-casting machines include the pipe mold and a means of rotating the mold at speeds sufficient to hold the molten iron against the mold wall by centrifugal force; delivering the iron to the inside of the mold, such as by a trough; applying inoculating material to the mold and/or iron; cooling the external surface of the mold; and extracting the solidified pipe (Figure 3-1).

At the beginning of a cast, a sand core that forms the inside contour of the pipe bell is inserted into the bell end of the mold and locked in place by one of several available mechanisms. For most casting machines, when the bell core is in place, the machine starts the rotation and delivers the mold over the length of the stationary trough until the spout end of the trough is near the bell core. Other casting machines differ in that the rotating mold is stationary and the trough is from a machine ladle designed and maintained to move through the mold. At the proper time, iron is poured into the upper end of the trough delivering iron at a constant rate throughout the pour. Following a dwell time sufficient to fill the bell cavity, the casting machine withdraws the mold from the trough at a controlled rate so that the iron is distributed evenly along the full length of the mold. Following the metal pour, mold rotation is continued until the newly formed pipe has solidified and cooled sufficiently to be removed. Spinning of the mold is then stopped and the pipe extracted either by holding the pipe stationary and pulling the mold away from it or by pulling the pipe out of the stationary mold with a pipe puller.

Preparations for the next casting cycle consist of removing any solid "splinters" from the bottom of the trough, recoating the inner surface of the mold with an inoculating dry spray, and placing a new core in the bell end. The dry spray is fed to

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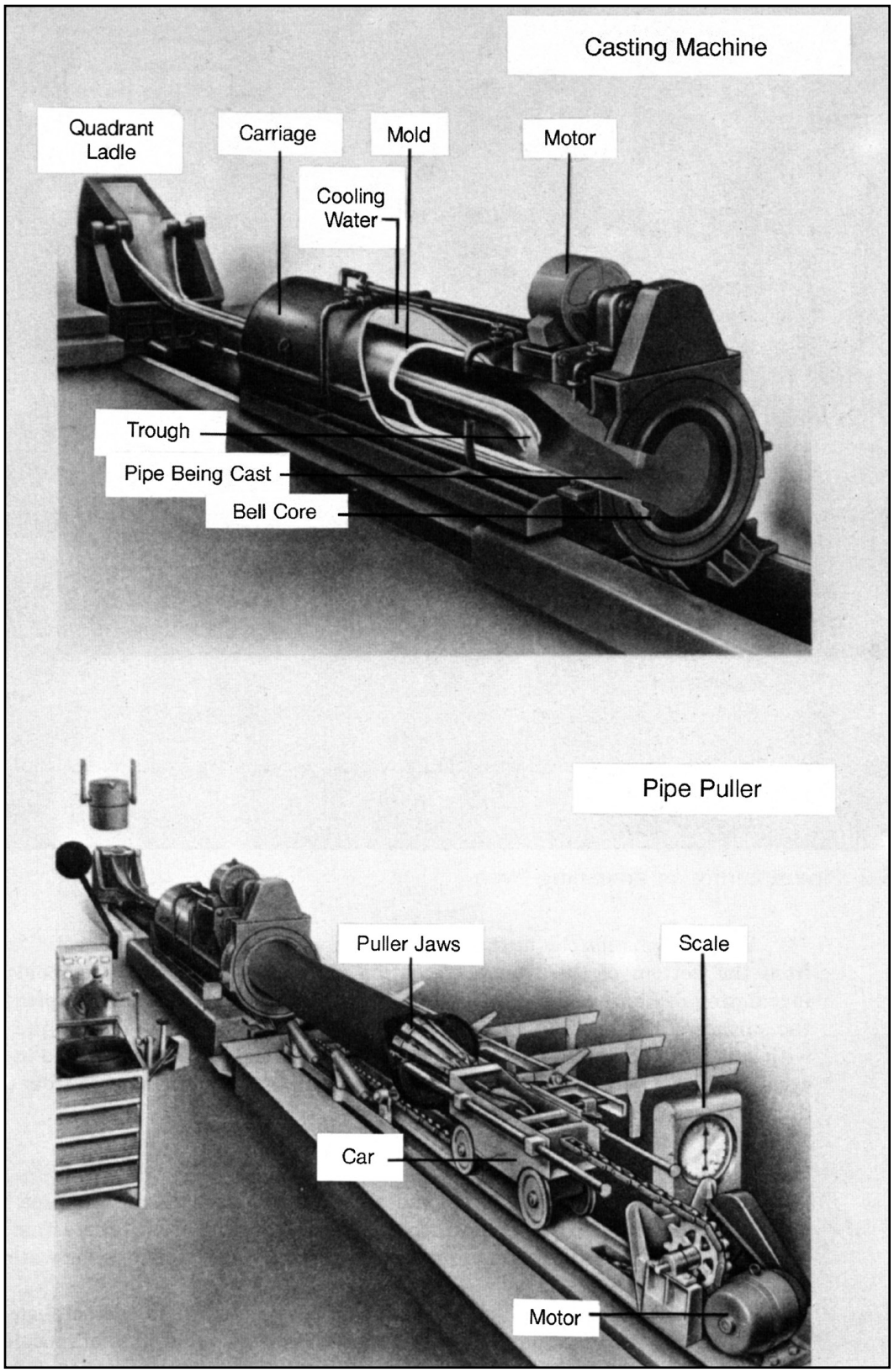


Figure 3-1 Elements of a casting machine

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the surface of the rotating mold through tubing mounted on the trough and supplied with exit ports near the spout. The spray is applied by running the trough through the mold in a stroke between casting cycles or just in front of the metal stream during the casting cycle.

3.1.4 Annealing

Because of the mold cooling and rapid iron solidification, the pipe must be annealed (heat treated) to produce the necessary proportion of ferrite that imparts strength, ductility, and impact properties required by specifications for water service (Figure 3-2).

The annealing times and temperatures necessary to accomplish carbide breakdown and ferritization depend on metal chemistry, the degree of inoculation the iron received prior to casting, and the influence of the solidification rate during casting. Pipe rapidly cooled by casting directly against the metal mold surface requires austenitizing at approximately 1,750˚F (954˚C) prior to a ferritizing treatment at approximately 1,400˚F (760˚C). Pipe cast against other surfaces cools more slowly and may require only the ferritizing treatment.

Modern annealing ovens are equipped with automatic controls for maintaining correct temperatures in heating and cooling zones, and for maintaining correct travel speed through the oven. Except in batch-type ovens in which pipe stands vertically (Figure 3-3), provisions must usually be made for rotating the pipe or supporting the pipe while at elevated temperatures. Pipe larger than 12 in. (305 mm) in diameter may be passed through a "rounder" that kneads the pipe between full-length rollers while it is still at an elevated temperature from the annealing treatment.

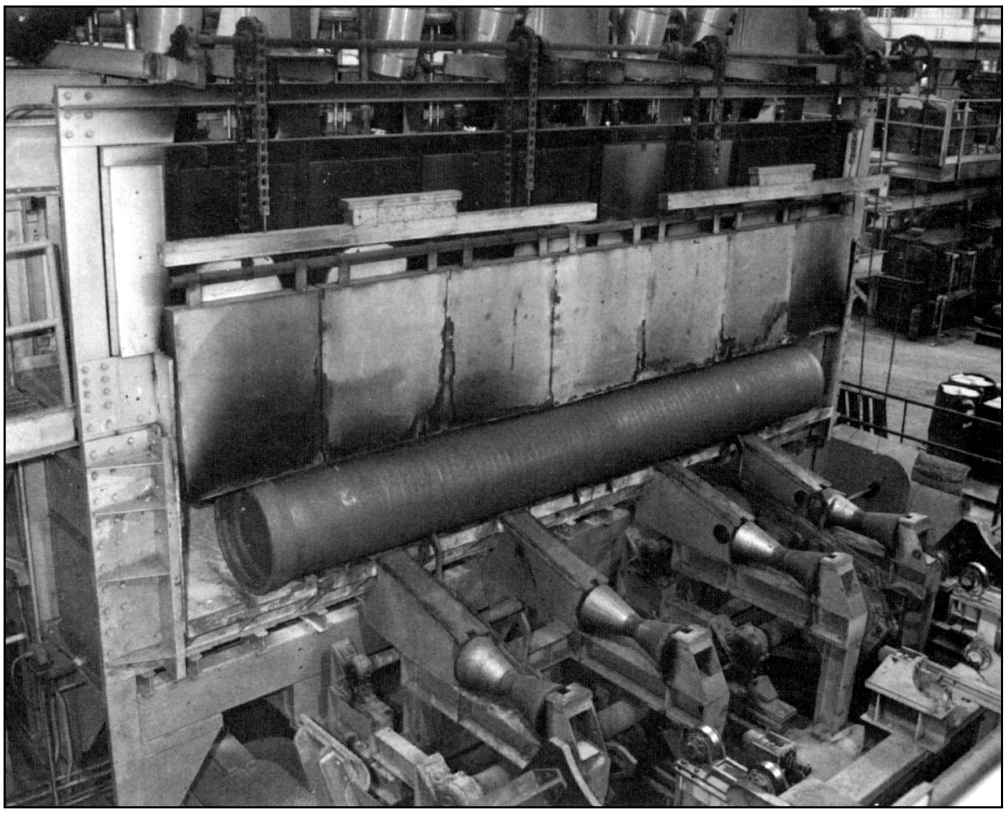


Figure 3-2 Pipe entering an annealing oven

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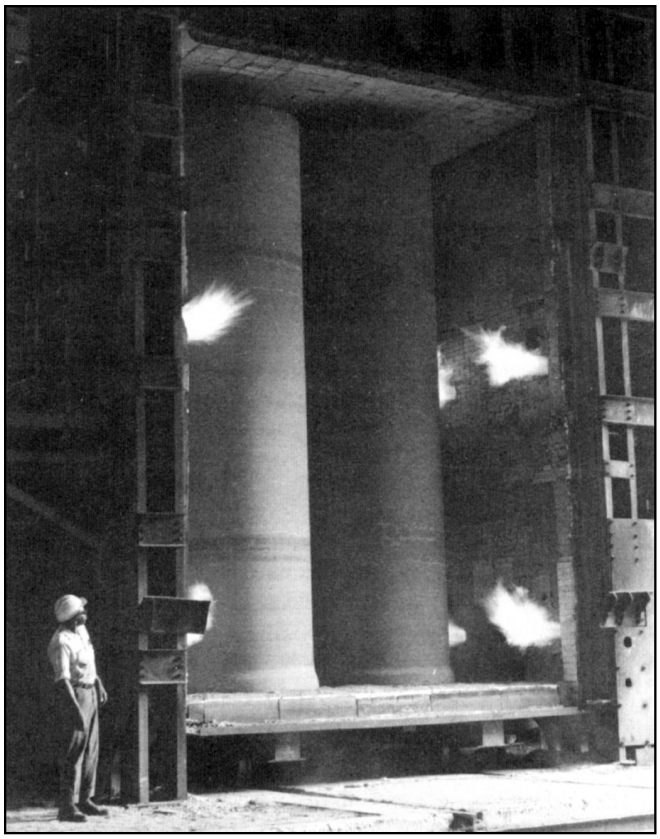


Figure 3-3 Vertical annealing furnace

3.2 TESTING

The annealing treatment relieves casting stresses, increases toughness, and improves ductility while maintaining required strength. The effectiveness of the annealing treatment, as well as the spheroidal properties of the graphite, are proven using performance tests. The types of tests required, test frequencies, and acceptance limits are specified in ANSI*/AWWA C151/A21.51.[1] The current edition of the standard requires that samples for 70˚F (21˚C) notched Charpy impact tests (ASTM† E23[2] as modified by AWWA C151) be taken during each operating hour, and that the samples be selected to represent the extremes of pipe diameters and thicknesses. Samples for tensile testing are required to be taken at least once during each casting period of approximately three hours. At least 10 percent of the required samples selected for Charpy testing must be also tested at –40˚F (–40˚C).

Acceptance values for the notched Charpy impact tests are a minimum of 7 ft-lb (9.49 J) at 70˚F (21˚C) and 3 ft-lb (4.07 J) at –40˚F (–40˚C). If a sound specimen fails to meet the minimum requirement, this indicates that the specimen contains excessive pearlite and/or carbides (ineffective anneal), excessive silicon, or degenerated graphite. A microscopic examination of the Charpy test bar can indicate which of the three imperfections, or combination thereof, caused the failure. Pipe with excessive pearlite

* American National Standards Institute, 25 W. 43rd St., Fourth Floor, New York, NY 10036-7406.

† ASTM International, 100 Barr Harbor Dr., West Conshohocken, PA 19428-2959.

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or carbide may be salvaged by further annealing treatments and retesting. However, pipe with degenerated graphite and excessive silicon content cannot be corrected by heat treatment and must be scrapped.

Acceptance values for tensile tests (ASTM E8)[3] are the following:

Tensile strength: 60,000 psi minimum (413.7×10^3 kPa)

Yield strength: 42,000 psi minimum (289.6×10^3 kPa)

Elongation: 10 percent minimum

A pipe sample that meets the required notched Charpy impact requirement with a sound specimen will rarely fail to meet the tensile requirement. When the results from a test fail to meet acceptance requirements, all pipe back to the last acceptable test are suspect and are bracketed for further investigation.

When pipe exits the annealing treatment, it may be internally ground to remove protrusions that may have formed on the inside surface by the centrifugal action during casting. In accordance with the requirements of ANSI/AWWA C151/A21.51, each pipe is hydrostatically tested at a minimum of 500 psi (3,450 kPa) for a minimum of 10 sec (Figure 3-4). In further compliance with the standard, each pipe is weighed and sufficient pipe is gauged inside the socket and outside the spigot to ensure that dimensional requirements are met.

Although there are many factors that must be controlled in proper balance, the centrifugal casting process has replaced all alternative methods of making ductile-iron pipe. In addition to its benefits of high productivity and economy, the process produces pipe with close dimensional control and a dense wall structure.

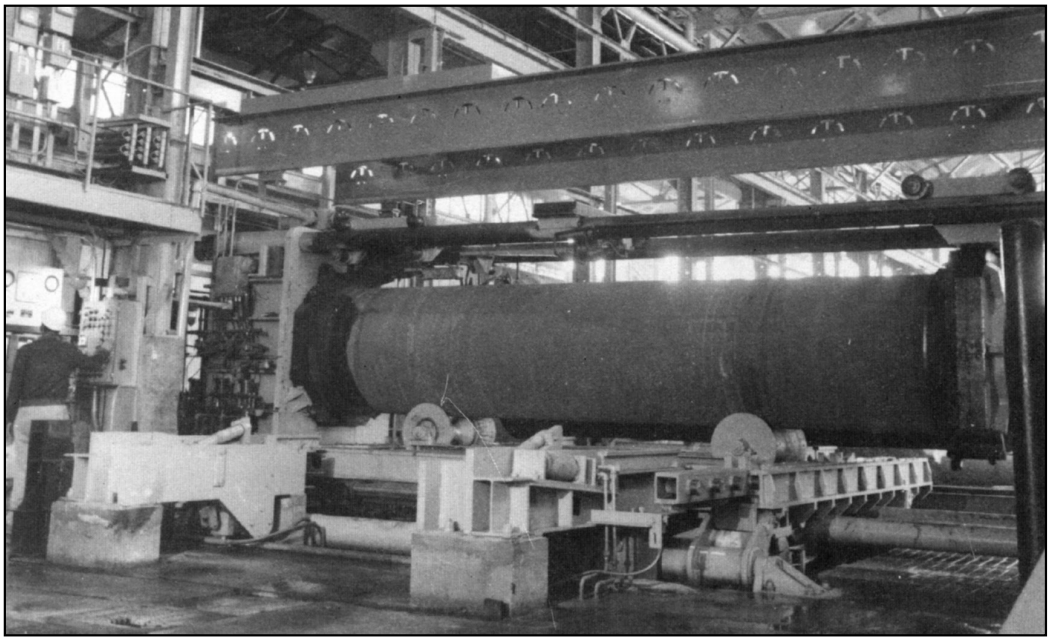


Figure 3-4 Hydrostatic testing of pipe to a minimum of 500 psi (3,450 kPa)

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3.3 FITTINGS TESTING

Fittings for ductile-iron pipe are cast by conventional foundry methods for static sand castings. Fittings of the older ANSI/AWWA C110/A21.10[4] designs are produced of either gray-iron or ductile-iron in sizes 3 in. through 48 in. (76 mm through 1,219 mm). Ductile-iron fittings of the newer compact design are produced in accordance with ANSI/AWWA C153/A21.53,[5] in the 3-in. through 64-in. (76-mm through 1,600-mm) sizes. Both fittings standards require that the iron used be tested for chemical and mechanical properties and that at least one sample be selected representing each period of approximately three hours, during which the melting unit is operated continuously.

Chemical limitations are 0.08 percent maximum phosphorus in ductile-iron fittings, and 0.15 percent maximum sulfur and 0.90 percent maximum phosphorus in gray-iron fittings. Control of the other chemical constituents is specified to meet the respective physical property requirements of these standards.

The most common acceptance test for the physical characteristics of ductile-iron fittings is a tensile test of specimens from (1) a separately cast coupon, (2) the castings runner bar system, or (3) the casting, conducted in accordance with ASTM A536.[6] The manufacturer of fittings must have records to demonstrate that such fittings meet the performance test requirements of the standard. The most common grade of iron is 70-50-05, with acceptance values as follows:

Tensile strength: 70,000 psi minimum (482.7×10^3 kPa)

Yield strength: 50,000 psi minimum (344.8×10^3 kPa)

Elongation: 5 percent minimum

Another permissible grade of iron is 60-42-10. The acceptance values of this 60-42-10 grade are the following:

Tensile strength: 60,000 psi minimum (413.7×10^3 kPa)

Yield strength: 42,000 psi minimum (289.6×10^3 kPa)

Elongation: 10 percent minimum

For gray-iron fittings, the mechanical properties may be determined by tensile tests conducted per ASTM A48/A48M.[7] The acceptance values for tensile tests shall be as shown in Table 3-1.

Table 3-1 Acceptance values for tensile tests

Iron Strength, *psi 1,000*	Fitting Size, *in.*	Minimum Tensile Strength, *psi*
25	3–14	25,000
30	14–24	30,000
30	20–48	30,000
35	16–24	35,000
35	20–36	35,000

NOTE: To convert inches (in.) to millimeters (mm), multiply by 25.4; to convert pounds per square inch (psi) to megapascal (MPa), multiply by 6.895×10^{-3}.

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ANSI/AWWA C153/A21.53, Standard for Ductile-Iron Compact Fittings for Water Service, requires that the manufacturer shall have qualified the design of the product by performing pressure tests on 90° bends and crosses of each size to demonstrate a minimum safety factor of three times the rated working pressure and shall have records to show the results of these tests. Tests of equal opening tees shall be substituted for tests of crosses if the manufacturer produces tees but not crosses.

REFERENCES

1. Standard for Ductile-Iron Pipe, Centrifugally Cast. ANSI/AWWA C151/A21.51. Denver, Colo.: American Water Works Association.
2. Standard Test Methods for Notched Bar Impact Testing of Metallic Materials. ASTM E23. West Conshohocken, Pa.: ASTM International.
3. Standard Test Methods for Tension Testing of Metallic Materials. ASTM E8. West Conshohocken, Pa.: ASTM International.
4. Standard for Ductile-Iron and Gray-Iron Fittings. ANSI/AWWA C110/A21.10. Denver, Colo.: American Water Works Association.
5. Standard for Ductile-Iron Compact Fittings for Water Service. ANSI/AWWA C153/A21.53. Denver, Colo.: American Water Works Association.
6. Standard Specification for Ductile Iron Castings. ASTM A536. West Conshohocken, Pa.: ASTM International.
7. Standard Specification for Gray Iron Castings. ASTM A48/A48M. West Conshohocken, Pa.: ASTM International.

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Chapter 4

Design

4.1 BACKGROUND

The design of ductile-iron pipe for most services requiring pressure pipe is described in ANSI*/AWWA C150/A21.50,[1] Standard for Thickness Design of Ductile-Iron Pipe. The design procedures published in this standard have evolved through the work of the A21 Committee on Ductile-Iron Pipe and Fittings (A21 Committee) of AWWA. Ductile-iron pipe has been carefully studied since it was introduced in the 1950s, and the A21 Committee has been provided with extensive test data on virtually all aspects of the material that could affect its performance. The A21 Committee meets periodically to review and update ANSI/AWWA C150/A21.50 and other standards concerning ductile-iron pipe and fittings.

The design of ductile-iron pipe is based on the flexible conduit theory developed in the 1940s by Professor M.G. Spangler[2] and others at Iowa State University and confirmed by tests conducted by E.C. Sears[3] in 1961 (Figure 4-1). Additional tests conducted in 1971 at Utah State University, as reported by R.K. Watkins and Harold Kennedy Jr.,[4] further confirmed the conservatism of the design method.

Briefly, the design procedure for ductile-iron pipe is as follows:

1. Design for external load (earth load plus truck or transient load).
2. Design for internal pressures (static or operating pressure plus water hammer allowance).
3. Use the larger resulting wall thickness.
4. Add a 0.08-in. (2.0-mm) service allowance.
5. Add a standard casting allowance.

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

* American National Standards Institute, 25 W. 43rd St., Fourth Floor, New York, NY 10036-7406.

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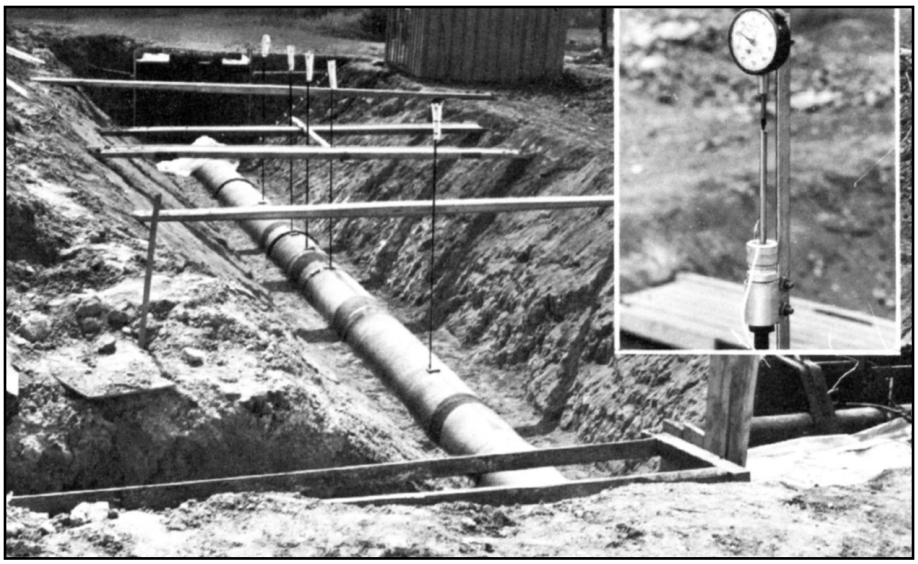


Figure 4-1 Performance test on 36-in. (914-mm) ductile-iron pipe with push-on joints

4.2 MAJOR DESIGN CRITERIA AND FORMULAS

The A21 Committee carefully chose the following criteria for use in calculating required thicknesses of ductile-iron pipe. Definitions of symbols used in Section 4.2 are provided in Section 4.2.1.

4.2.1 Nomenclature

A	=	Outside radius of pipe. For A in ft, D in in.: $A = D/24$ (For A in m, D in mm: $A = D/2{,}000$)
a	=	Conversion factor. For lb/ft^2 to psi: $a = 144$ (for kN/m^2 to kPa: $a = 1$)
B	=	1.5 ft (0.457 m)
b	=	Effective pipe length: 36 in. (0.914 m)
C	=	Surface load factor
D	=	Outside diameter, in. (mm) (see Table 4-4)
E	=	Modulus of elasticity: 24×10^6 psi (165.5×10^3 kPa)
E'	=	Modulus of soil reaction, psi (kPa) (see Table 4-2)
F	=	Impact factor: 1.5
f	=	Design bending stress: 48,000 psi (331×10^3 kPa)
H	=	Depth of cover, ft (m)
K_b	=	Bending moment coefficient (see Table 4-2)
K_x	=	Deflection coefficient (see Table 4-2)
P	=	Wheel load: 16,000 lb (71,170 N)
P_e	=	Earth load, psi (kPa)
P_i	=	Design internal pressure, in psi (kPa): $P_i = 2\ (P_w + P_s)$
P_w	=	Working pressure, psi (kPa)
P_s	=	Standard surge allowance, 100 psi (689 kPa)

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P_t	=	Truck load, in psi (kPa)
P_v	=	Trench load, in psi (kPa): $P_v = P_e + P_t$
R	=	Reduction factor, which takes into account that the part of the pipe directly below the wheels is aided in carrying the truck load by adjacent parts of the pipe that receive little or no load from the wheels (see Table 4-1)
S	=	Minimum yield strength in tension: 42,000 psi (289.6×10^3 kPa)
t	=	Net thickness, in. (mm)
t_1	=	Minimum manufacturing thickness. In in.: $t_1 = t + 0.08$ (in mm: $t_1 = t + 2.0$)
w	=	Soil weight: 120 lb/ft^3 (18.85 kN/m^3)
Δx	=	Design deflection, in./in. (mm/mm): $\Delta x = 0.03D$

4.2.2 Earth Load

Earth load is based on the prism load formula (Eq 4-1). This formula gives the weight of the column of earth directly above the pipe. This is the maximum earth load that can be imposed on a flexible conduit in a ditch condition because, in most cases, this load is reduced by the support of the sidefill soil. The unit weight of the backfill soil is conservatively assumed to be 120 lb/ft^3 (18.85 kN/m^3).

$$P_e = \frac{wH}{a} \tag{4-1}$$

4.2.3 Truck Loads

Truck loads are computed by Eq 4-2 using the surface load factors from Eq 4-3 and the reduction factor R from Table 4-1 for a single American Association of State Highway and Transportation Officials (AASHTO) H-20 truck on unpaved road or flexible pavement, 16,000-lb (71,170-N) wheel load, and an impact factor of 1.5 at all depths. The surface load factor C calculated by using Eq 4-3 is based on a single concentrated wheel load centered over an effective pipe length of 3 ft (0.914 m). The reduction factor R takes into account that the part of the pipe directly below the wheels is aided in carrying the truck load by adjacent parts of the pipe that receive little or no load from the wheels.

$$P_t = RF\frac{CP}{bD} \tag{4-2}$$

$$C = 1 - \frac{2}{\pi}\operatorname{Arcsin}\left(H\sqrt{\frac{A^2+B^2+H^2}{(A^2+H^2)(B^2+H^2)}}\right) + \left(\frac{2}{\pi}\right)\left(\frac{A\times H\times B}{\sqrt{A^2+H^2+B^2}}\right)\left(\frac{1}{A^2+H^2}+\frac{1}{B^2+H^2}\right) \tag{4-3}$$

NOTE: Angles are in radians.

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Table 4-1 Reduction factors, *R*, for truck load calculations

Nominal Pipe Size, *in.*	Depth of Cover, *ft*			
	<4	4–7	7–10	>10
	Reduction Factor			
3–12	1.00	1.00	1.00	1.00
14	0.92	1.00	1.00	1.00
16	0.88	0.95	1.00	1.00
18	0.85	0.90	1.00	1.00
20	0.83	0.90	0.95	1.00
24–30	0.81	0.85	0.95	1.00
36–64	0.80	0.85	0.90	1.00

NOTE: To convert inches (in.) to millimeters (mm), multiply by 25.4; to convert feet (ft) to meters (m), multiply by 0.3048.

4.2.4 External Load Design

The net wall thickness required for external load is based on two design considerations: limitation of ring bending stress* and ring deflection. When a trench load of sufficient magnitude is applied, ductile-iron pipe can deflect amply to develop passive resistance from the sidefill soil, thereby transmitting part of the trench load to the sidefill soil. Thus, the load-carrying capacity of ductile-iron pipe is a function of soil and ring stiffness. In addition, a reaction equal to the vertical trench load exerted on the pipe develops where the pipe embeds into the trench. This reaction is distributed almost uniformly over the width of bedding of the pipe. The width of bedding is the effective contact area on the pipe bottom where bedding support is sufficient to develop an equal reaction to the vertical trench load. The greater the width of bedding, the greater the load-carrying capacity of the pipe. Therefore, certain design criteria dependent on the width of bedding and on the passive resistance of the sidefill soil are essential to calculating ring bending stress and ring deflection of ductile-iron pipe and have been established from test data for the standard laying conditions shown in Figure 4-2.

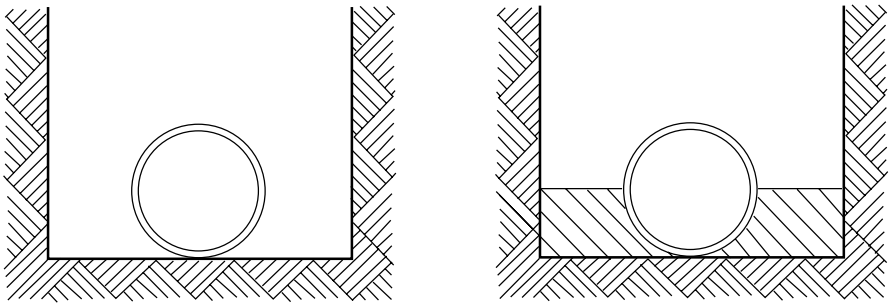
Net thicknesses are computed using the bending stress and deflection equations described in the following section. The larger of the two thicknesses is then selected as the net thickness required for external load design.

4.2.5 Bending Stress Design

Ring bending stress is limited to 48,000 psi (331.0×10^3 kPa). This design value provides ample safety factors on material strength as discussed later in this chapter. Equation 4-4 is used to calculate the trench load required to develop bending stress at the pipe invert.

* Most other flexible conduit material designs do not include calculations for bending stress caused by external load (with accompanying ring deflection). Ductile-iron pipe design conservatively includes calculations for bending stress caused by external loads, which in some cases controls the design thickness.

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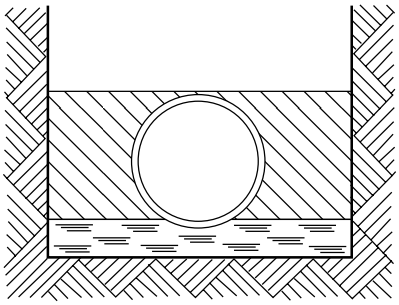


Type 1*

Flat-bottom trench† with loose backfill.

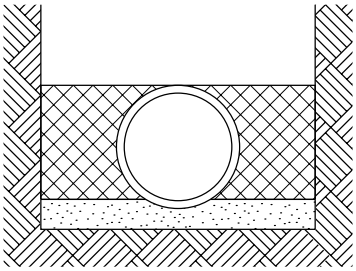
Type 2

Flat-bottom trench† with loose backfill lightly consolidated to centerline of pipe.



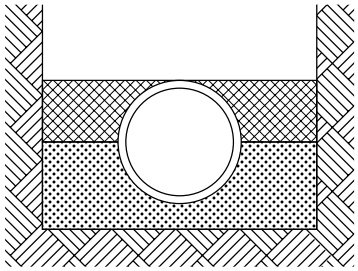
Type 3

Pipe bedded in 4-in. (100-mm) minimum loose soil‡ with backfill lightly consolidated to top of pipe.



Type 4

Pipe bedded in sand, gravel, or crushed stone to depth of $^1/_8$ pipe diameter, 4-in. (100-mm) minimum, with backfill compacted to top of pipe. (Approximately 80% Standard Proctor, AASHTO§ T-99)



Type 5

Pipe bedded to its centerline in compacted granular material, 4-in. (100-mm) minimum under pipe. Compacted granular** or select material‡ to top of pipe. (Approximately 90% Standard Proctor, AASHTO§ T-99)

NOTES: 1) Consideration of the pipe-zone embedment conditions included in this figure may be influenced by factors other than pipe strength. See chapter 11 for additional information on pipe bedding and backfill.

2) To convert pounds per square inch (psi) to kilopascals (kPa), multiply by 6.895.

* For 14-in. (356-mm) and larger pipe, consideration should be given to the use of laying conditions other than Type 1.

† Flat bottom is defined as undisturbed earth.

‡ Loose soil or select material is defined as native soil excavated from the trench, free of rocks, foreign materials, and frozen earth.

§ AASHTO T-99 "Standard Method of Test for the Moisture-Density Relations of Soils Using 5.5 lb. (2.5 kg) Rammer and a 12 in. (305 mm) Drop." Available from the American Association of State Highway and Transportation Officials, 444 N. Capitol St. N.W., Suite 225, Washington, DC 20001.

**Granular materials are defined per the AASHTO Soil Classification System (ASTM D3282) or the United Soil Classification System (ASTM D2487), with the exception that gravel bedding/backfill adjacent to the pipe is limited to 2-in. maximum particle size per ANSI/AWWA C600.

3) For design values, see Table 4-2.

Figure 4-2 Laying conditions for ductile-iron pipe

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$$P_v = \frac{f}{3\left(\frac{D}{t}\right)\left(\frac{D}{t}-1\right)\left(K_b - \frac{K_x}{\left(\frac{8E}{E'\left(\frac{D}{t}-1\right)^3}+0.732\right)}\right)} \quad (4\text{-}4)$$

4.2.6 Deflection Design

The maximum allowable ring deflection for cement–mortar-lined ductile-iron pipe is 3 percent* of the outside diameter. This design deflection provides a conservative safety factor against failure of the cement–mortar lining, because much larger deflections can be sustained without damage to the pipe wall or cement–mortar lining. Equation 4-5 is derived from Spangler's deflection equation and is used to calculate the trench load required to develop the design ring deflection of the pipe outside diameter.

$$P_v = \left(\frac{\left(\frac{\Delta x}{D}\right)}{12K_x}\right)\left(\frac{8E}{\left(\frac{D}{t_1}-1\right)^3}+0.732E'\right) \quad (4\text{-}5)$$

The conservatism of this design is demonstrated in several ways. Tests in which cement–mortar-lined ductile-iron pipe were loaded to obtain large deflections proved that the cement–mortar lining will not fail by deflections of up to 6 percent and greater; thus the 3 percent design limit provides ample safety factors, as explained later in this chapter. Furthermore, prism earth loads used in ductile-iron pipe design exceed Spangler's flexible pipe loads, which are used in most other flexible pipe designs.

The maximum ring deflection normally occurs in the relatively short period after installation and before pressurization. After pressurization, deflection is substantially reduced by rerounding. Actual trench tests have shown that no further deflection occurs while the pipe is under pressure; in fact, a slight reduction in deflection occurs with time, probably as a result of a slight yielding of the earth above the pipe as the earth is forced upward by the rerounding force in the pipe. (Internal pressures in most modern pipelines exceed by many magnitudes the external trench load P_v.) Tests have also proved that if pressure is relieved in a line after it has been operating, the deflections are unlikely to return to values obtained before initial pressurization. This is because of the settling of soil into voids left at the sides and haunches of the rerounded pipe and a subsequent increase in lateral soil support as the soil consolidates with time.

4.2.7 Standard Laying Conditions

As indicated previously, certain factors dependent on the specified type of laying condition are essential to the design of ductile-iron pipe for external loads. Two of these factors, bending moment coefficient, K_b, and deflection coefficient, K_x, depend on the width of bedding at the pipe bottom. The angle subtended by the width of bedding is commonly referred to as the bedding angle. The remaining factor is modulus of soil reaction, E', which is a measure of the passive resistance that can be developed in the

* Ductile-iron pipe with flexible linings is designed with a 5 percent maximum allowable deflection per ASTM A746, Standard Specification for Ductile Iron Gravity Sewer Pipe, and ASTM A716, Standard Specification for Ductile Iron Culvert Pipe.

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sidefill soil. To facilitate design calculations, conservative factors have been established from reliable test data for five standard laying conditions as shown in Table 4-2. Thus, a designer has a great deal of flexibility in selecting the most economical combination of wall thickness and bedding requirements.

It is important to note that use of the equations for bending stress and deflection to determine net thickness is somewhat lengthy and time-consuming. To expedite calculations, design tables that provide diameter–thickness ratios for a wide range of trench loads have been developed from these equations for all five standard laying conditions and are included in ANSI/AWWA C150/A21.50. With these design tables, a designer need only know trench load and desired laying conditions to compute net thickness required for bending stress and deflection designs. An example calculation is also included in the standard.

Table 4-2 Design values for standard laying conditions

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

NOTES: 1) Consideration of the pipe-zone embedment conditions included in this table may be influenced by factors other than pipe strength. For additional information, see ANSI/AWWA C600, Standard for Installation of Ductile-Iron Water Mains and Their Appurtenances.

2) To convert pounds per square inch (psi) to kilopascals (kPa), multiply by 6.895.

*See Figure 4-2.

†For pipe 14 in. (350 mm) and larger, consideration should be given to the use of laying conditions other than Type 1.

‡Flat-bottom is defined as "undisturbed earth."

§Loose soil or select material is defined as "native soil excavated from the trench, free of rocks, foreign material, and frozen earth."

**AASHTO T-99, "Standard Methods of Test for the Moisture-Density Relations of Soils Using a 5.5 lb (2.5 kg) Rammer and a 12-in. (305-mm) Drop," available from the American Association of State Highway and Transportation Officials, 444 N. Capitol St. N.W., Washington, DC 20001.

††Granular materials are defined per AASHTO Soil Classification System (ASTM D3282) or the Unified Soil Classification System (ASTM D2487), with the exception that gravel bedding/backfill adjacent to the pipe is limited to 2-in. maximum particle size per ANSI/AWWA C600.

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4.2.8 Internal Pressure Design

The hoop stress formula (Eq 4-6) is used to calculate net thickness required for internal pressure. In the formula, the internal pressure design is equal to a safety factor of 2.0 times the sum of working pressure and surge allowance. The surge allowance used in standard ductile-iron pipe design is 100 psi (689 kPa), which is adequate for most water service applications. (See chapter 9 for a discussion on water hammer or surge.) If anticipated surge pressures are other than 100 psi, the designer should use the actual anticipated pressure.

$$t = \frac{P_i D}{2S} \qquad (4\text{-}6)$$

Where:

t	=	net pipe wall thickness, in. (mm)
P_i	=	design internal pressure, psi (kPa) = 2 ($P_w + P_s$)
P_w	=	working pressure, psi (kPa)
P_s	=	standard surge allowance, 100 psi (689 kPa)*
D	=	outside diameter of pipe, in. (mm)
S	=	minimum yield strength in tension = 42,000 psi (289,590 kPa)

4.2.9 Standard Allowances

Once the net thickness requirement has been determined (the larger net thickness from either external load design or internal pressure design), certain allowances are added to obtain the total calculated thickness requirement. To obtain the minimum manufacturing thickness, a service allowance of 0.08 in. (2.0 mm) for all pipe sizes is added to provide an additional safety factor against any possible thickness reduction from surface imperfections or minor damage received during handling and installation. A standard casting allowance is then added to provide for possible manufacturing variations. Casting allowance depends on the pipe size as shown in Table 4-3.

4.2.10 Standard Pressure Classes

Ductile-iron pipe is manufactured in standard pressure classes varying from Class 150 to Class 350 in 50 psi (344.75 kPa) increments, depending on pipe size. Nominal thicknesses for these standard classes are shown in Table 4-4. Once the total calculated thickness has been determined, a standard pressure class should be selected for ordering and specifying. When the calculated thickness is between two standard thicknesses, the larger of the two should be selected. On specific projects, manufacturers may be willing to provide pipe with thicknesses that fall between those of standard classes.

4.2.11 Standard Selection Table

Using the design procedure described, Table 4-5, a standard selection table, was developed that gives maximum depth of cover and rated working pressure for each standard pressure class and laying condition. This table has been provided so that a designer may select, rather than calculate, the appropriate pressure class and laying conditions for a given design application.

* If anticipated surge pressures are greater than 100 psi (689 kPa), the maximum anticipated pressure must be used.

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Table 4-3 Allowances for casting tolerance

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

NOTE: To convert inches (in.) to millimeters (mm), multiply by 25.4.

Table 4-4 Standard pressure classes of ductile-iron pipe

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

NOTE: Pressure classes are defined as the rated water working pressure of the pipe in pounds per square inch (psi). The thicknesses shown are adequate for the rated water working pressure plus a surge allowance of 100 psi (689 kPa). Calculations are based on a minimum yield strength in tension of 42,000 psi (289.6×10^3 kPa) and a 2.0 safety factor times the sum of working pressure and 100 psi (689 kPa) surge allowance.

To convert inches (in.) to millimeters (mm), multiply by 25.4.

Thickness can be calculated for rated water working pressure and surges other than those indicated by use of the formula shown in ANSI/AWWA C150/A21.50.

Ductile-iron pipe is available for water working pressures greater than 350 psi (2,413 kPa).

Pipe is available with thicknesses greater than Pressure Class 350. See Table 4-6.

Lowest nominal thicknesses shown in ANSI/AWWA C115/A21.15 for threaded flanged pipe are still required; lowest nominal thicknesses shown in ANSI/AWWA C606 for pipe with grooved and shouldered joints are still required.

* Calculated thicknesses for these sizes and pressure ratings are less than those shown above. (See Table 13 of ANSI/AWWA C150/A21.50 for actual calculated thicknesses.) Presently these are the lowest nominal thicknesses available in these sizes.

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4.2.12 Special Thickness Classes

Prior to the 1991 revision of AWWA C150/A21.50 and AWWA C151/A21.51,[5] standard thickness classes of ductile-iron pipe were identified as Classes 50 through 56. These are now designated as special thickness classes and continue to be available for design conditions not covered in Tables 4-4 and 4-5. Wall thicknesses for these special thickness classes are shown in Table 4-6, and their rated working pressures and maximum depths of cover are presented in Table 4-7.

Table 4-5 Rated working pressure and maximum depth of cover, standard pressure classes

Nominal Pipe Size, *in.*	Pressure* Class, *psi*	Nominal Thickness, *in.*	Laying Conditions				
			Type 1 Trench	Type 2 Trench	Type 3 Trench	Type 4 Trench	Type 5 Trench
			Maximum Depth of Cover,† *ft*				
3	350	0.25	78	88	99	100‡	100‡
4	350	0.25	53	61	69	85	100‡
6	350	0.25	26	31	37	47	65
8	350	0.25	16	20	25	34	50
10	350	0.26	11§	15	19	28	45
12	350	0.28	10§	15	19	28	44
14	250	0.28	**	11§	15	23	36
	300	0.30	**	13	17	26	42
	350	0.31	**	14	19	27	44
16	250	0.30	**	11§	15	24	34
	300	0.32	**	13	17	26	39
	350	0.34	**	15	20	28	44
18	250	0.31	**	10§	14	22	31
	300	0.34	**	13	17	26	36
	350	0.36	**	15	19	28	41
20	250	0.33	**	10	14	22	30
	300	0.36	**	13	17	26	35
	350	0.38	**	15	19	28	38
24	200	0.33	**	8§	12	17	25
	250	0.37	**	11	15	20	29
	300	0.40	**	13	17	24	32
	350	0.43	**	15	19	28	37

NOTE: To convert inches (in.) to millimeters (mm), multiply by 25.4; to convert feet (ft) to meters (m), multiply by 0.3048; to convert pounds per square inch (psi) to kilopascals (kPa), multiply by 6.895.

*Ductile-iron pipe is adequate for the rated working pressure indicated for each nominal size plus a surge allowance of 100 psi (689 kPa). Calculations are based on a 2.0 safety factor times the sum of working pressure and 100 psi (689 kPa) surge allowance. (See ANSI/AWWA C150/A21.50 for design formulae.) Ductile-iron pipe for working pressures higher than 350 psi (2,413 kPa) is available.

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

‡Calculated maximum depth of cover exceeds 100 ft (30.5 m).

§Minimum allowable depth of cover is 3 ft (0.9 m).

**For pipe 14 in. (350 mm) and larger, consideration should be given to the use of laying conditions other than Type 1.

Table continued next page

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Table 4-5 Rated working pressure and maximum depth of cover, standard pressure classes (continued)

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

NOTE: To convert inches (in.) to millimeters (mm), multiply by 25.4; to convert feet (ft) to meters (m), multiply by 0.3048; to convert pounds per square inch (psi) to kilopascals (kPa), multiply by 6.895.

*Ductile-iron pipe is adequate for the rated working pressure indicated for each nominal size plus a surge allowance of 100 psi (689 kPa). Calculations are based on a 2.0 safety factor times the sum of working pressure and 100 psi (689 kPa) surge allowance. (See ANSI/AWWA C150/A21.50 for design formulae.) Ductile-iron pipe for working pressures higher than 350 psi (2,413 kPa) is available.

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

‡Calculated maximum depth of cover exceeds 100 ft (30.5 m).

§Minimum allowable depth of cover is 3 ft (0.9 m).

**For pipe 14 in. (350 mm) and larger, consideration should be given to the use of laying conditions other than Type 1.

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Table 4-6 Special thickness classes of ductile-iron pipe

Nominal Pipe Size, *in.*	Outside Diameter, *in.*	Special Thickness Class						
		50	51	52	53	54	55	56
		Thickness, *in.*						
3	3.96	—	0.25	0.28	0.31	0.34	0.37	0.40
4	4.80	—	0.26	0.29	0.32	0.35	0.38	0.41
6	6.90	0.25	0.28	0.31	0.34	0.37	0.40	0.43
8	9.05	0.27	0.30	0.33	0.36	0.39	0.42	0.45
10	11.10	0.29	0.32	0.35	0.38	0.41	0.44	0.47
12	13.20	0.31	0.34	0.37	0.40	0.43	0.46	0.49
14	15.30	0.33	0.36	0.39	0.42	0.45	0.48	0.51
16	17.40	0.34	0.37	0.40	0.43	0.46	0.49	0.52
18	19.50	0.35	0.38	0.41	0.44	0.47	0.50	0.53
20	21.60	0.36	0.39	0.42	0.45	0.48	0.51	0.54
24	25.80	0.38	0.41	0.44	0.47	0.50	0.53	0.56
30	32.00	0.39	0.43	0.47	0.51	0.55	0.59	0.63
36	38.30	0.43	0.48	0.53	0.58	0.63	0.68	0.73
42	44.50	0.47	0.53	0.59	0.65	0.71	0.77	0.83
48	50.80	0.51	0.58	0.65	0.72	0.79	0.86	0.93
54	57.56	0.57	0.65	0.73	0.81	0.89	0.97	1.05

NOTE: To convert inches (in.) to millimeters (mm), multiply by 25.4.

4.2.13 Safety Factor

The safety factor for internal pressure is 2.0 based on minimum yield strength of ductile iron in tension. For external loads, two safety factors are specified: 1.5 based on minimum ring yield strength and at least 2.0 based on ring ultimate strength. Also, the design ring deflection provides a safety factor of at least 2.0 based on test data regarding deflections required to cause failure in cement–mortar linings.

These safety factors are used to establish minimum design criteria and should not be confused with the total available or actual safety factor of ductile-iron pipe, which is generally much greater than the minimum because of the following:

- Minimum manufacturing thickness for small-size pipes (3-in. through 8-in. diameter) is even greater than what is required per the basic design for a 350 psi working pressure rating.
- The design criteria for ductile-iron pipe are not based on performance limits associated with actual failure of the pipe wall.
- Specified safety factors are used to calculate net wall thickness requirements, after which both service allowance and casting allowance are added.
- The yield strength of ductile-iron pipe will consistently exceed the minimum values specified for design.
- Ductile-iron pipe can sustain stresses considerably higher than yield strength determined by standard test methods without damage to the pipe wall.
- Design considerations dependent on laying conditions were established on a conservative basis.

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Table 4-7 Rated working pressure and maximum depth of cover, special thickness classes

Nominal Pipe Size, *in.*	Special Thickness Class	Nominal Thickness, *in.*	Rated Water Working Pressure, *psi*[*]	Laying Condition				
				Type 1	Type 2	Type 3	Type 4	Type 5
				Maximum Depth of Cover,[†] *ft*				
3	51	0.25	350[+]	78	88	99	100[‡]	100[‡]
	52	0.28	350[+]	100[‡]	100[‡]	100[‡]	100[‡]	100[‡]
	53	0.31	350[+]	100[‡]	100[‡]	100[‡]	100[‡]	100[‡]
	54	0.34	350[+]	100[‡]	100[‡]	100[‡]	100[‡]	100[‡]
	55	0.37	350[+]	100[‡]	100[‡]	100[‡]	100[‡]	100[‡]
	56	0.40	350[+]	100[‡]	100[‡]	100[‡]	100[‡]	100[‡]
4	51	0.26	350[+]	62	71	80	98	100[‡]
	52	0.29	350[+]	94	100[‡]	100[‡]	100[‡]	100[‡]
	53	0.32	350[+]	100[‡]	100[‡]	100[‡]	100[‡]	100[‡]
	54	0.35	350[+]	100[‡]	100[‡]	100[‡]	100[‡]	100[‡]
	55	0.38	350[+]	100[‡]	100[‡]	100[‡]	100[‡]	100[‡]
	56	0.41	350[+]	100[‡]	100[‡]	100[‡]	100[‡]	100[‡]
6	50	0.25	350[+]	26	31	37	47	65
	51	0.28	350[+]	40	47	53	67	88
	52	0.31	350[+]	58	66	75	92	100[‡]
	53	0.34	350[+]	78	89	100[‡]	100[‡]	100[‡]
	54	0.37	350[+]	100[‡]	100[‡]	100[‡]	100[‡]	100[‡]
	55	0.40	350[+]	100[‡]	100[‡]	100[‡]	100[‡]	100[‡]
	56	0.43	350[+]	100[‡]	100[‡]	100[‡]	100[‡]	100[‡]
8	50	0.27	350[+]	21	26	31	40	57
	51	0.30	350[+]	30	36	42	53	71
	52	0.33	350[+]	41	48	55	69	90
	53	0.36	350[+]	55	63	71	88	100[‡]
	54	0.39	350[+]	70	79	90	100[‡]	100[‡]
	55	0.42	350[+]	87	99	100[‡]	100[‡]	100[‡]
	56	0.45	350[+]	100[‡]	100[‡]	100[‡]	100[‡]	100[‡]
10	50	0.29	350[+]	16	21	25	35	51
	51	0.32	350[+]	23	28	33	43	60
	52	0.35	350[+]	31	36	42	54	72
	53	0.38	350[+]	40	46	53	66	87
	54	0.41	350[+]	50	58	65	81	100[‡]
	55	0.44	350[+]	62	71	80	98	100[‡]
	56	0.47	350[+]	75	85	96	100[‡]	100[‡]

NOTE: To convert inches (in.) to millimeters (mm), multiply by 25.4; to convert feet (ft) to meters (m), multiply by 0.3048; to convert pounds per square inch (psi) to kilopascals (kPa), multiply by 6.895.

[*] Ductile-iron pipe is adequate for the rated water working pressure indicated for each nominal size plus a surge allowance of 100 psi (689 kPa). Calculations are based on a 2.0 safety factor times the sum of working pressure and 100 psi (689 kPa) surge allowance. Calculations are rounded to the nearest 5 psi.

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

[+] The calculated actual rated water working pressure exceeds 350 psi (2,413 kPa). Ductile-iron pipe for rated water working pressures higher than 350 psi (2,413 kPa) is available.

[‡] Calculated maximum depth of cover exceeds 100 ft (30.5 m).

[§] Minimum allowable depth of cover is 3 ft (0.9 m).

[**] For pipe 14 in. (350 mm) and larger, consideration should be given to the use of laying conditions other Type 1.

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