CHAPTER A8

PRESTRESSED CONCRETE CYLINDER PIPE (PCCP) AND FITTINGS

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INTRODUCTION

History

Prestressed concrete cylinder pipe (PCCP) has been manufactured in the United States since 1942. An American Water Works Association (AWWA) tentative standard was developed in 1949 and was made a permanent standard in 1952. Since that time, this standard has been reviewed and updated on a regular basis. PCCP offers the specifier and owner numerous advantages, including ease of installation, custom-designed fittings, superior corrosion resistance, high-flow characteristics, low maintenance costs, and product support by the manufacturer. PCCP is used extensively for a wide range of project types both in the United States and around the world.

There are three other types of concrete pressure pipe: reinforced concrete cylinder pipe (referenced in the AWWA Standard C300[1]), reinforced concrete noncylinder pipe (referenced in the AWWA Standard C302[2]), and pretensioned concrete cylinder pipe (referenced in the AWWA Standard C303[3]).

Terminology and Definitions

Spigot ring— the protruding end of a PCCP joint which contains a shaped groove to retain the O-ring rubber gasket (refer to Fig. A8.1)

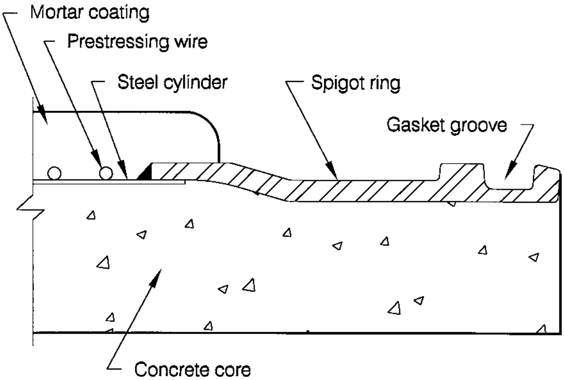

FIGURE A8.1 Spigot ring.

Bell ring—	the receiving portion of a PCCP joint (refer to Fig. A8.2)
O-ring gasket—	rubber ring of circular cross-section which, when compressed into the spigot-ring groove by the bell ring, provides a water-tight seal
Laying length—	a measure of a pipe or fitting's length along its axis for purposes of advancing the length of a pipeline
Working pressure—	the long-term, steady-state internal pressure
Transient pressure—	the incremental change in internal pressure in a pipeline, which is usually of short duration, that is caused by a relatively sudden change in flow velocity

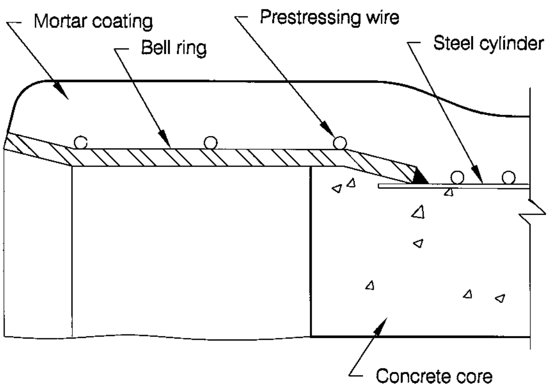

FIGURE A8.2 Bell ring.

Field test pressure— an internal pressure applied to a pipeline or portion of a pipeline to test its structural and water-tight performance

External dead load— an applied load to a pipe which is generally constant, such as earth weight, foundation loads, and so on

External live load— an applied load to a pipe which is transient in nature and usually of short duration, such as motor vehicles

Applications for Prestressed Concrete Pressure Pipe

PCCP is the most widely used type of concrete pressure pipe for the transport of water and wastewater in the United States and the world. Uses include raw and potable water transmission lines, water distribution systems, gravity and pressure sewers, power plant cooling systems, industrial process lines, water and wastewater treatment plant process lines, sewer outfalls, raw water intakes, and impoundment-dam spillway conduits. It is a versatile pipe that can be installed in the normal direct-buried condition; as an aerial crossing over canals, rivers, and other obstacles; or subaqueously in both freshwater and seawater.

Reference Standards

Table A8.1 summarizes the standards covering the design and manufacture of PCCP. The AWWA standards in Table A8.1 include reference to other standards published by the American Society for Testing and Materials (ASTM), American Society of Mechanical Engineers (ASME), American Concrete Institute (ACI),

TABLE A8.1 Reference Standards

Title	Purpose
American National Standards Institute/ American Water Works Association C301 Prestressed Concrete Pressure Pipe, Steel-Cylinder Type[4]	Covers the manufacturing process for PCCP, including raw material specifications, manufacturing techniques, and testing procedures.
American National Standards Institute/ American Water Works Association C304 Design of Prestressed Concrete Cylinder Pipe[5]	Covers the design process for PCCP.
American Water Works Association Manual of Water Supply Practices "M9—Concrete Pressure Pipe" [6]	Provides general information regarding the design, manufacturing, and use of PCCP. Also includes information on the other types of concrete pressure pipe: reinforced cylinder pipe, reinforced noncylinder pipe, and pretensioned concrete cylinder pipe.

American Iron and Steel Institute (AISI), American Welding Society (AWS), and American Association of State Highway and Transportation Officials (AASHTO).

DESCRIPTION

Pipe Types

Prestressed concrete cylinder pipe consists of a structural, high-strength concrete core, a steel cylinder with steel joint rings welded at each end providing watertightness, steel prestressing wire, and a portland cement-rich mortar coating. Two

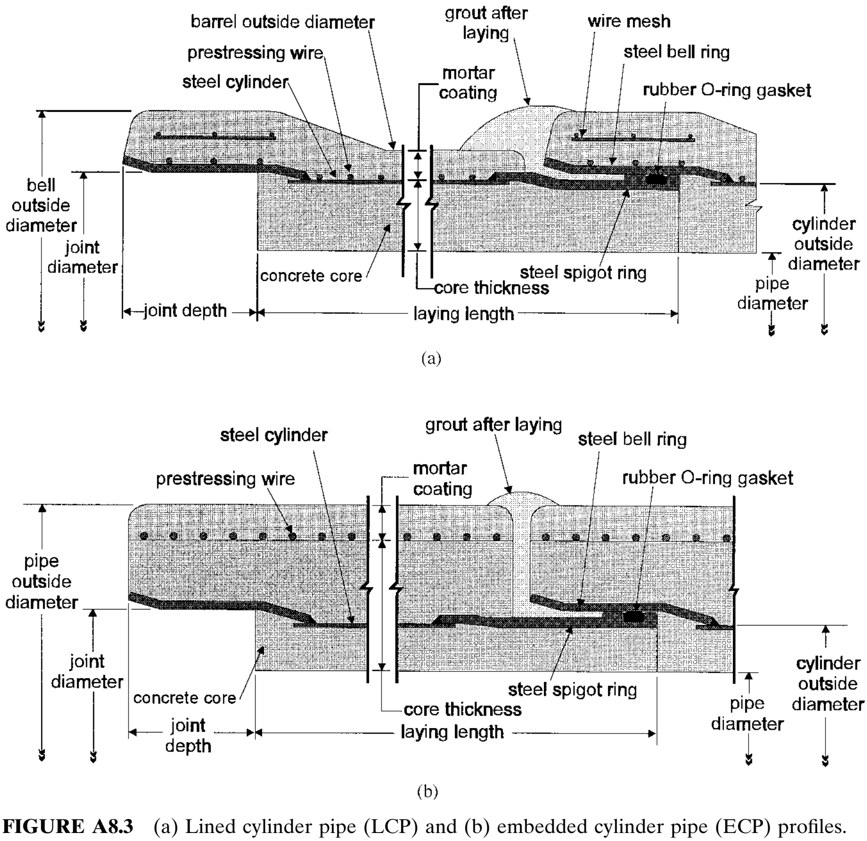

FIGURE A8.3 (a) Lined cylinder pipe (LCP) and (b) embedded cylinder pipe (ECP) profiles.

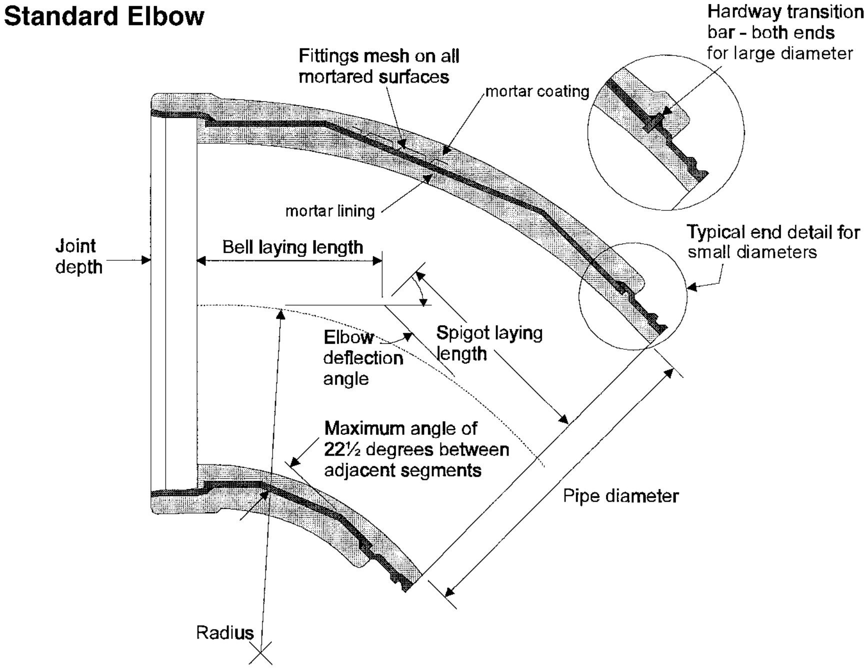

FIGURE A8.4 Typical elbow fitting.

types of PCCP are manufactured: lined cylinder pipe (LCP), which is detailed in Fig. A8.3a and embedded cylinder pipe (ECP), which is detailed in Fig. A8.3b. Lined cylinder pipe has the entire concrete core placed inside the steel cylinder. The cured concrete core and steel cylinder are then helically wrapped with prestressing wire, which is subsequently coated with cement mortar. Embedded cylinder pipe has the concrete core placed both outside and inside the steel cylinder by a vertical casting operation. The cured concrete core and steel cylinder are then helically wrapped with prestressing wire and, as LCP, is coated with cement mortar.

Available Size Ranges

LCP is normally manufactured with inside diameters ranging from NPS 16 (DN 400) through NPS 48 (DN 1200), although larger sizes have been made. ECP is normally manufactured with inside diameters ranging from NPS 54 (DN 1350) through NPS 144 (DN 3600), but diameters smaller and larger than this range are possible. The nominal laying length for pipe up to and including NPS 114 (DN 2850) is usually 20 ft (6 m), and 16 ft (4.9 m) for larger sizes. These diameter ranges and laying lengths can sometimes vary by manufacturer, so the user should check with suppliers on specific sizes. In larger sizes, the laying length can be controlled

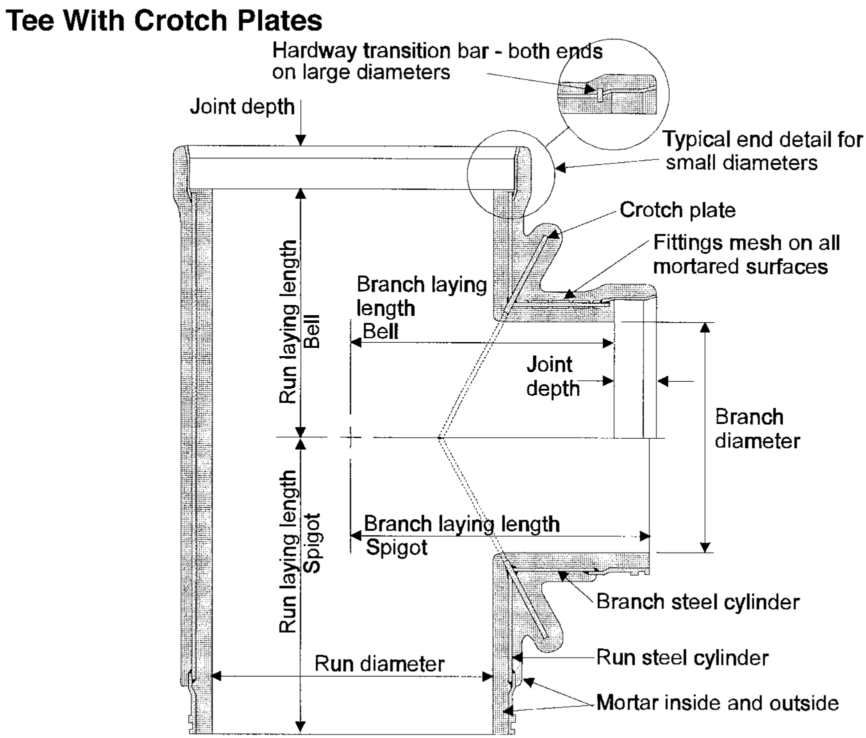

FIGURE A8.5 Typical tee fitting.

by the weight of the piece and the manufacturer's and installing contractor's ability to handle it.

Fittings and Special Pipe

A wide range of fittings and special pipe lengths are available for all types of project requirements. Fittings are manufactured from steel plate which is cut, rolled, and welded to form the required shape. The completed steel shell is lined and coated with portland cement mortar for corrosion protection. Each fitting is designed for the same external load and internal pressure as the adjoining pipe. Common fittings are elbows, tees, wyes, reducers, wall pieces, and adapters. Adapters are needed for connections to other types of joints such as flanges, mechanical joints, and couplings. Figures A8.4 through A8.7 show the general configurations of elbows, tees, concentric reducers, and flange adapters.

Special pipe consists of prestressed pipe lengths with additional features such as outlets or beveled ends. Prestressed pieces with a laying length shorter than the standard constitute a special pipe that can be supplied to match specific job requirements.

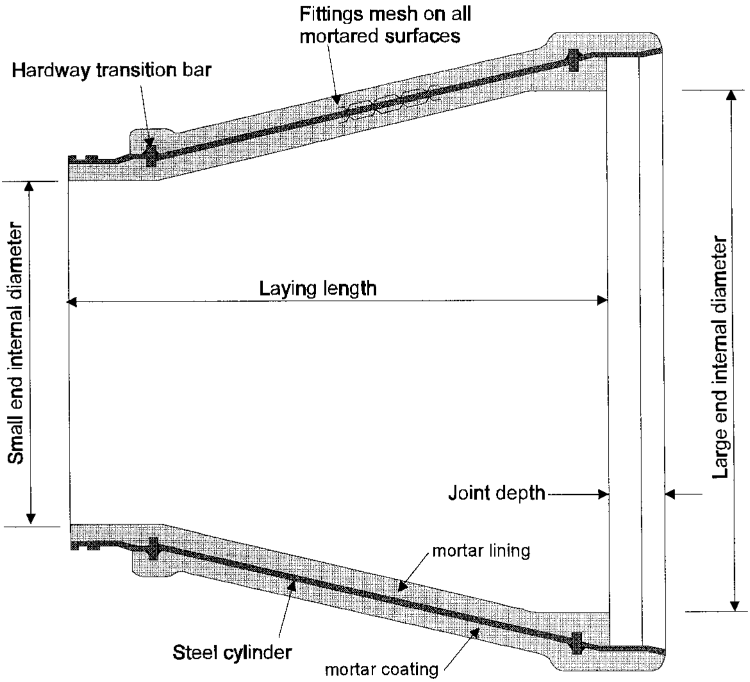

FIGURE A8.6 Typical concentric reducer fitting.

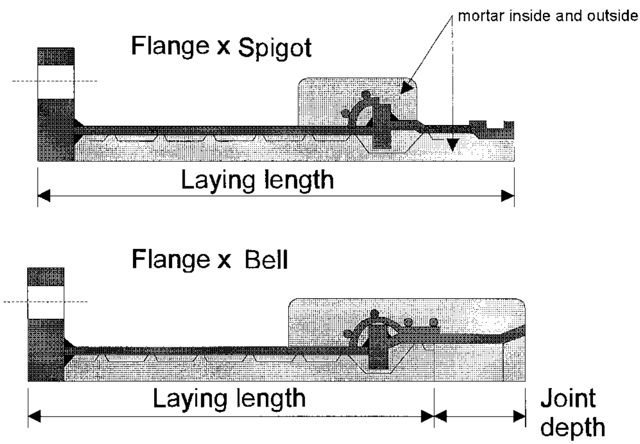

FIGURE A8.7 Typical flange adapters.

DESIGN

Design Parameters

PCCP is designed as a rigid structure to resist the simultaneous application of external loads and internal pressures. External dead loads normally encountered are earth loads, foundation loads, or surcharges applied at the ground surface. External live loads are caused by vehicular traffic, railroads, or construction equipment. The weight of the pipe and the weight of water inside the pipe are also considered in the design procedure. Internal pressures used for design are the working pressure, transient pressure, and the field hydrostatic test pressure. The working pressure should be the expected steady-state internal pressure for the system. The transient pressure is the expected internal pressure over and above the working pressure that can occur during surge (water hammer) conditions. If the purchaser does not include a transient pressure in the specifications, the AWWA C304[5] design standard requires that, as a minimum, the transient pressure allowance be 40 percent of the working pressure, or 40 psi (0.27 MPa), whichever is greater. A postconstruction hydrostatic pressure test is usually conducted to confirm the structural integrity and watertightness of the completed system. In the absence of a field hydrostatic test pressure specified by the purchaser, the AWWA C304 design standard requires the use of a test pressure of 1.2 times the working pressure. Support under the pipe provided by the bedding material must also be used in the design procedure. Various suggested bedding types are shown in the AWWA C304 design standard.

The pipe purchaser's plans and specifications should contain as a minimum the following design parameters for PCCP:

Earth cover over the top of the pipe

Expected live load (normally AASHTO HS20 truck loading configuration)

Internal working pressure

Internal transient pressure allowance

Field hydrostatic test pressure

Bedding type

The pipe and fittings manufacturer will design and manufacture the pipe and fittings to comply with the pressures and loadings specified.

Hydraulics

Energy use in pipeline operation can be greatly reduced during the design stage. Head losses due to pipe wall friction are among the most manageable causes of energy consumption for pipelines which use pumps. These losses can be minimized with the use of pipe which has excellent long-term hydraulic characteristics and by selecting a large enough pipe diameter to avoid high-flow velocities which accelerate energy costs. Energy savings resulting from these design decisions will help reduce operating costs each year throughout the life of the pipeline.

Flow Formulas

Over the years, many empirical flow formulas have been proposed. The Hazen-Williams formula, shown below, was first published by Allen Hazen and Gardner S. Williams in 1905, and continues to be the most widely used for pressure pipe systems.

$$V = 0.550C_h\left(\frac{h_L}{L}\right)^{0.54} d^{0.632} \quad \text{(A8.1)}$$

where V = mean velocity, ft/s
C_h = Hazen-Williams flow coefficient
d = inside pipe diameter, ft
h_L = head loss, ft
L = pipe length, ft

$$V = 0.3549C_h\left(\frac{h_L}{L}\right)^{0.54} d^{0.632} \quad \text{(A8.1M)}$$

where V = mean velocity, m/s
C_h = Hazen-Williams flow coefficient
d = inside pipe diameter, m
h_L = head loss, m
L = pipe length, m

A statistical analysis of 67 flow tests of concrete pressure lines was made by Swanson and Reed and published in the January 1963 AWWA Journal.[7] Some of this pipe was manufactured as early as 1895. This report presented a "best fit" mean deviation comparison with the well-known formulas by Hazen-Williams, Morris, Moody, and Scobey. The authors concluded that the Hazen-Williams expression for head loss most closely matched the test results for the range of velocities normally encountered in water transmission. The average mean deviation between calculated and observed losses was lowest for the Hazen-Williams formula. A regression analysis least-squares method was used to develop a correlation equation for the Hazen-Williams "C_h" term for concrete pipe, as follows:

$$C_h = 139.3 + 2.028d \quad \text{(A8.2)}$$

where d = inside pipe diameter, ft

$$C_h = 139.3 + 6.654d \quad \text{(A8.2M)}$$

where d = inside pipe diameter, m

The Hazen-Williams flow formula can be rewritten in a more convenient form where head loss is expressed in terms of flow velocity.

Head loss in ft:

$$h_L = 3.021\frac{L}{d^{1.167}}\left(\frac{V}{C_h}\right)^{1.852} \quad \text{(A8.3)}$$

Head loss in m:

$$h_L = 6.8102\frac{L}{d^{1.167}}\left(\frac{V}{C_h}\right)^{1.852} \quad \text{(A8.3M)}$$

Head Losses Due to Fittings

While head losses due to fittings are generally a minor portion of the overall head loss in a pipeline, they can be important in certain applications such as treatment plants when the length of a line is short and the number of fittings is high. These head losses occur in elbows, reducers, enlargements, valves, and other fittings in the pipeline. The rational method of calculating these losses assumes full turbulence and expresses the loss in terms of velocity head. This expression is

$$h_L = C_L\frac{V^2}{2g} \quad \text{(A8.4)}$$

where h_L = head loss, ft (m)
V = velocity, ft/s (m/s)
C_L = a dimensionless coefficient
g = acceleration due to gravity, 32.2 ft/s^2 (9.81 m/s^2)

Values of "C_L" commonly used for design purposes for a variety of fittings and appurtenances, along with a more comprehensive treatment of hydraulics, are included in the AWWA manual "M9—Concrete Pressure Pipe."[6]

MANUFACTURE

Figure A8.8 illustrates the various steps in the manufacturing process for PCCP.

Figure A8.9 shows the various steps in the manufacturing process for fittings. The AWWA standard C301[4] provides a comprehensive description of the manufacturing requirements for pipe and fittings. The purchaser should require, in the specifications, that all pipe and fittings be manufactured per the AWWA C301 standard.

Quality Assurance

All PCCP manufacturers should establish quality assurance departments within the pipe plant to provide step-by-step attention to all production procedures and assure that all machinery and equipment is operating properly. Incoming raw materials must be carefully inspected and tested for compliance with the governing standards. The AWWA C301 standard contains the testing methods to be used and acceptance criteria for all raw materials to be incorporated into the pipe and fittings.

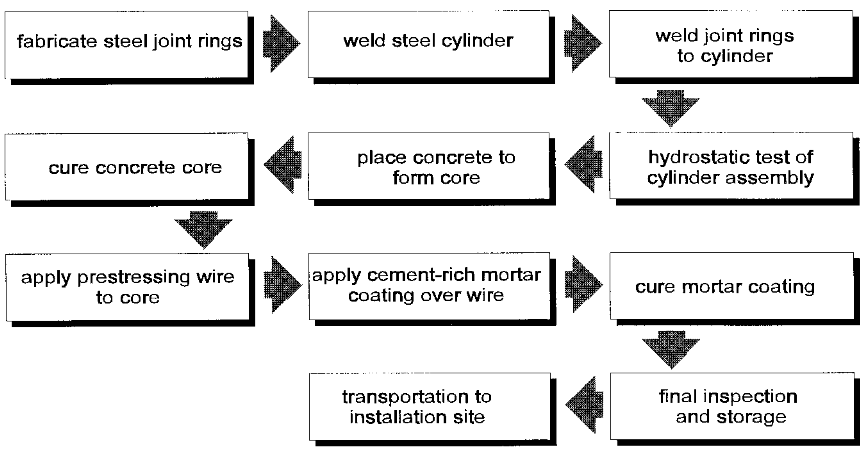

FIGURE A8.8 PCCP manufacturing process.

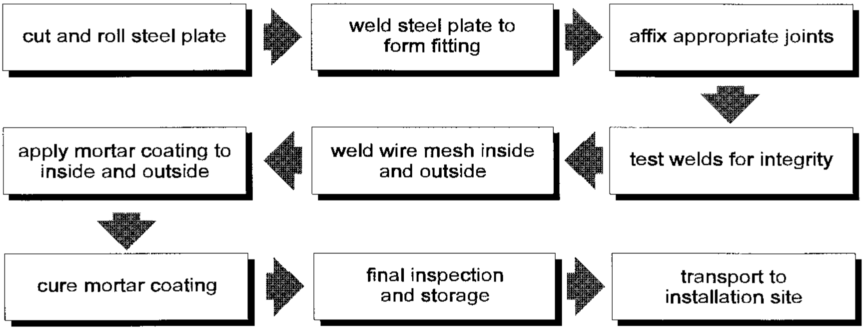

FIGURE A8.9 Fittings manufacturing process.

JOINTS

Rubber O-ring Bell and Spigot Joint

Figures A8.3a and A8.3b show a cross-section of the typical LCP and ECP bell and spigot joint. As can be seen, an O-ring rubber gasket is compressed into the spigot groove by the bell ring when assembled to form a water-tight seal. Portland

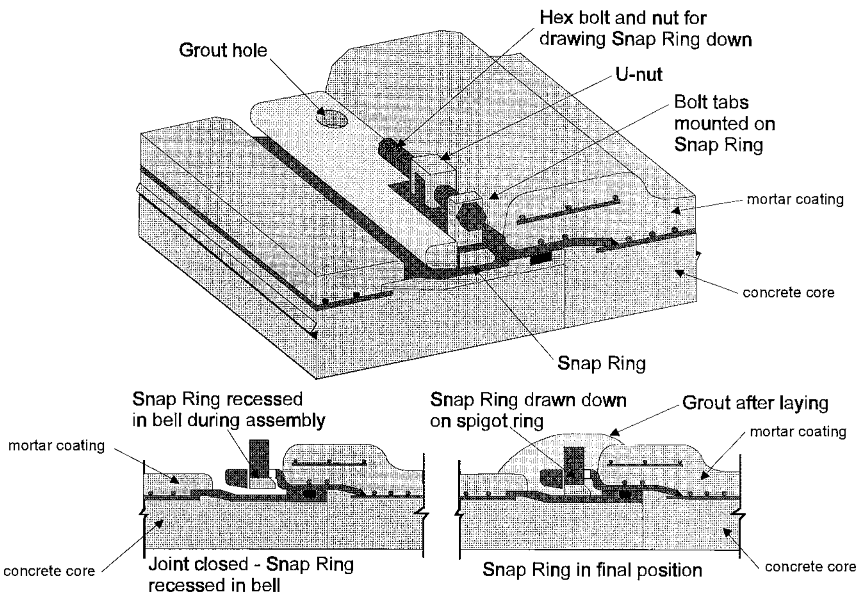

FIGURE A8.10 Snap Ring® restrained joint.

cement grout is poured into a fabric band (diaper) by the installer to provide corrosion protection.

Restrained Joints

Figure A8.10 depicts a Snap Ring® type restrained joint and Fig. A8.11 a harness clamp type restrained joint. These joints can be used to resist axial tensile forces on the pipe due to unbalanced thrusts caused by internal pressure at fittings such as elbows, tees, and bulkheads. The Snap Ring joint incorporates a split ring which is preassembled in the manufacturing plant so that it is recessed into a groove in the bell ring. After the spigot is pushed home into the bell, the installer tightens a single bolt which draws the split ring down around the shank of the spigot ring. This effectively locks the joint together. The harness clamp joint utilizes a two-part clamp which engages bars on the bell and spigot rings. After the spigot is pushed home into the bell, the installer places the clamp halves over the harness bars, securing them with bolts and nuts. The clamp installed in this manner locks the joint together.

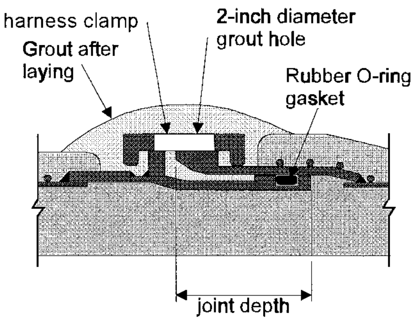

FIGURE A8.11a Lined cylinder pipe harness clamp restrained joint.

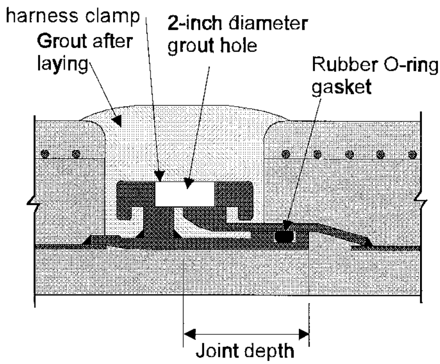

FIGURE A8.11b Embedded cylinder pipe harness clamp restrained joint.

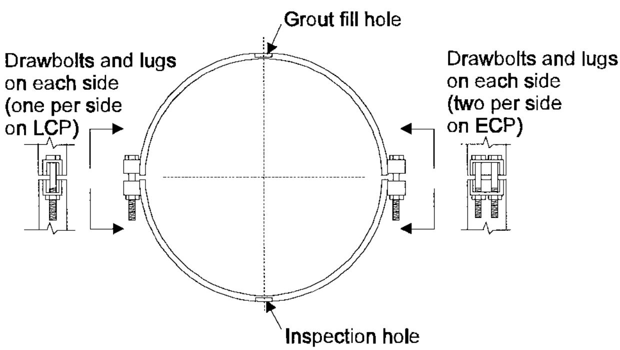

FIGURE A8.11c Harness clamp.

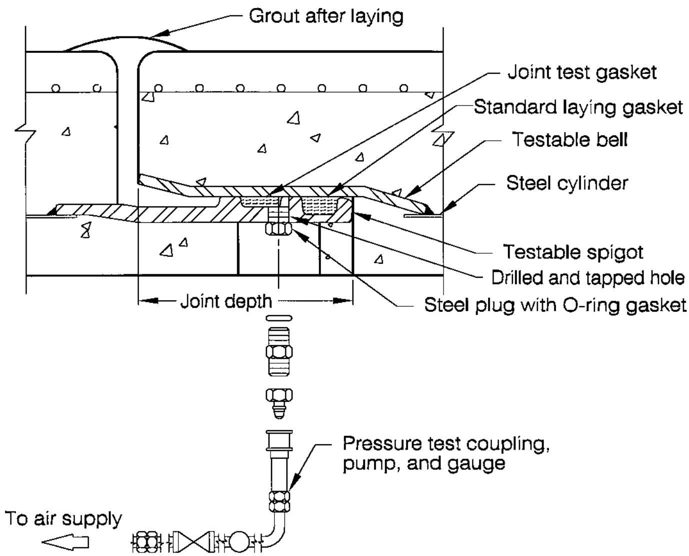

FIGURE A8.12 Testable joint.

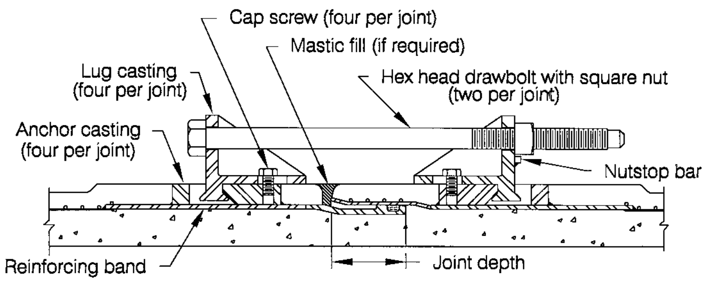

FIGURE A8.13a Lined cylinder pipe.

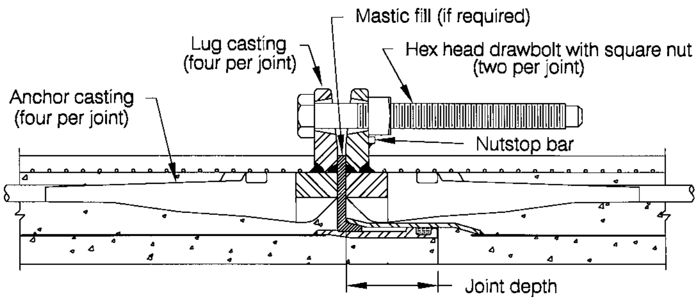

FIGURE A8.13b Embedded cylinder pipe.

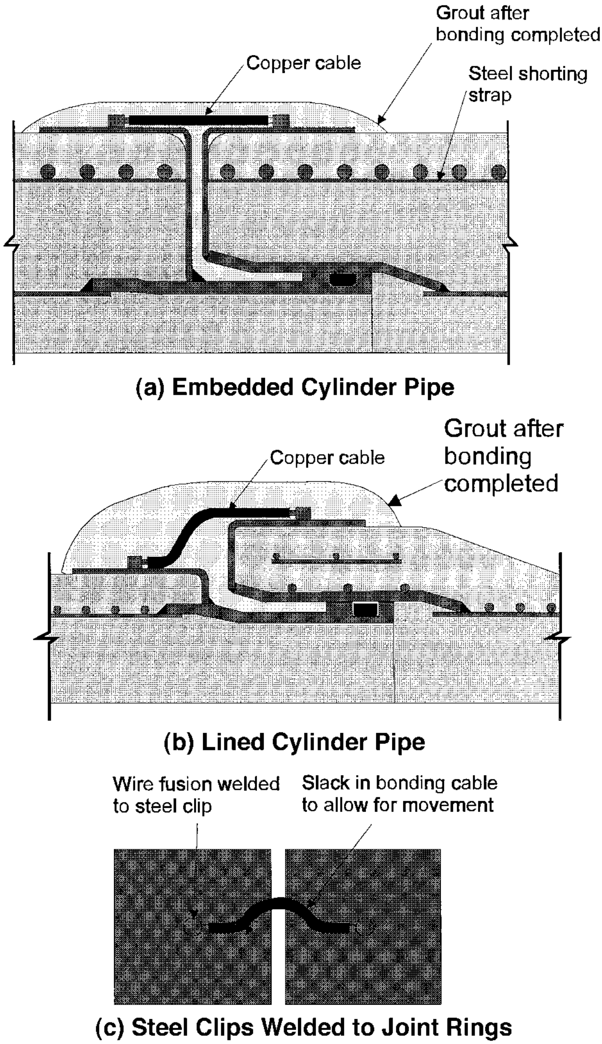

FIGURE A8.14 Bonded joint. Exothermic fusion welded copper cable method.

Testable Joints

Figure A8.12 shows a joint configuration which allows for testing the joint seal without the need to fill the pipeline with water. These joints are normally used when pipe is installed in a manner that necessitates immediate verification of the gasket seal. This feature is sometimes necessary for certain pipelines in power, industrial, water, and wastewater plants; for pipe in tunnel casings; and for subaqueous pipelines. This can be an effective tool for finding a problem with a joint seal at the time it can most easily be corrected. Testable joints are normally available in diameters NPS 54 (DN 1350) and larger. However, some manufacturers may be able to supply them in smaller diameters. Testable joints should not be considered a replacement for postconstruction hydrostatic pressure tests since they do not confirm the overall system integrity (restrained joints or concrete thrust blocks) and watertightness of connecting appurtenances such as valves and access manholes.

Other types of special joints available for PCCP include subaqueous joints and bonded joints. Subaqueous joints, depicted in Figs. A8.13a and A8.13b, are designed to facilitate jointing underwater by divers. They normally incorporate external lug and drawbolt assemblies. Bonded joints, shown in Figs. A8.14a, A8.14b, and A8.14c, are designed to provide electrical continuity across the joint for the future monitoring of electrical activity on the pipeline or for the application of cathodic protection.

INSTALLATION

Pipe Handling and Storage

A crane or backhoe outfitted with a steel cable sling may be used to unload pipe unless the pipe has a special exterior coating that could be damaged by a steel cable sling. In such cases, a fabric sling should be used. Multiple slings are often used in handling large pipe and fittings. Pipe can be stored directly on the ground in nonfreezing conditions. If freezing conditions are expected, the pipe should be set on wooden timbers off the ground to prevent the pipe from becoming frozen to the ground. Rubber gaskets should be stored in a cool place, out of the sun, away from fuel oil, gasoline, electric motors, and any other environment that can damage rubber.

Excavation and Bedding Preparation

In most cases, the trench is excavated to be long enough for one section of pipe. The trench should be wide enough to allow installing personnel adequate room to work at the sides of the pipe. Pipe should not be laid directly on rocks or other unyielding foundation. Refer to the AWWA C304 standard for the bedding and backfill requirements for PCCP.

Jointing

Just prior to jointing, the steel joint rings should be carefully cleaned and the rubber gasket and contact surfaces of the joint rings lubricated. Only lubricant recommended by the pipe manufacturer should be used. Once the joint ends are properly prepared and the rubber gasket is in place on the spigot, the ends are aligned so the spigot will enter the bell squarely. Then the spigot is pushed home with a smooth, continuous motion. The position of the gasket is then checked in the manner recommended by the pipe manufacturer. A fabric band is secured around the exterior joint recess to receive the portland cement grout for corrosion protection.

Backfilling

After the joint has been assembled and the exterior joint recess has been grouted, the pipe can be backfilled to grade. In general, the requirements for backfilling rigid PCCP will not be as critical as for flexible types of pipe such as steel, plastic, and ductile iron. The backfill in contact with the pipe should not contain large rocks, clods, or excessive organic material.

Field Hydrostatic Testing

In most situations, a post-construction hydrostatic pressure test of the completed pipeline is required before final acceptance by the owner. For very long lines, it may be convenient to test shorter sections as they are completed rather than wait and test the entire project at one time. This test can verify the overall system integrity such as the restrained joints or thrust blocks and the watertightness of the connecting appurtenances such as valves, access manholes, and outlets.

Repair

Occasionally, damage may occur in the field due to impacts from construction equipment or other objects. Minor damage can usually be repaired in the field by qualified personnel. Major damage may require shipment of the piece back to the manufacturing plant for repair or replacement. Before attempting any repairs in the field, the pipe manufacturer should be consulted for specific recommendations and assistance.

Special Installation Situations

During the design phase of some projects, areas of unstable soil conditions and crossings of small rivers, streams, or canals should be identified. In these cases, a pier support arrangement for the pipe may be needed. The pipe for this application must be designed and manufactured to span the supports and to resist the concentrated load applied to the pipe at the support.

PCCP to be placed underwater such as for intakes, outfalls, or lake and river crossings may require special consideration for joining pipe underwater by divers. PCCP to be used for subaqueous lines may have modifications made to the joints to allow for joint engaging assemblies such as drawbolts, or special devices may be used which create a vacuum force to pull the joint home while the pipe's weight is supported by a barge-mounted crane. In either case, it may be advantageous to use longer pipe lengths in order to minimize the number of underwater joint assemblies.

The concrete and mortar linings and coatings specified in the AWWA C301 standard provide ample corrosion protection in most buried environments. There are, however, certain conditions where the ability of the concrete and mortar to provide a passivating environment around the embedded steel may need to be supplemented. Additional protective measures may be needed in these instances. These conditions include

- High chloride environment
- Stray current interference

- High sulfate environments
- Severe acid conditions
- Aggressive carbon dioxide
- Atmospheric exposure
- Connections to other pipelines

Refer to the AWWA manual "M9—Concrete Pressure Pipe"[6] for further information on the identification and evaluation of these conditions. The pipe manufacturer should also be consulted for specific recommendations and availability of supplemental protective measures.

Tapping Prestressed Concrete Cylinder Pipe

Outlets, tees, and wyes can be built into the pipe when their need is identified at the time the project is designed. When unforeseen circumstances occur that require outlets, connections, or branch lines on already installed pipe, tapping of PCCP can be done.

Tapping PCCP for connecting outlets after a pipeline is installed is a common occurrence on most public works projects. Taps can easily be made on PCCP. In

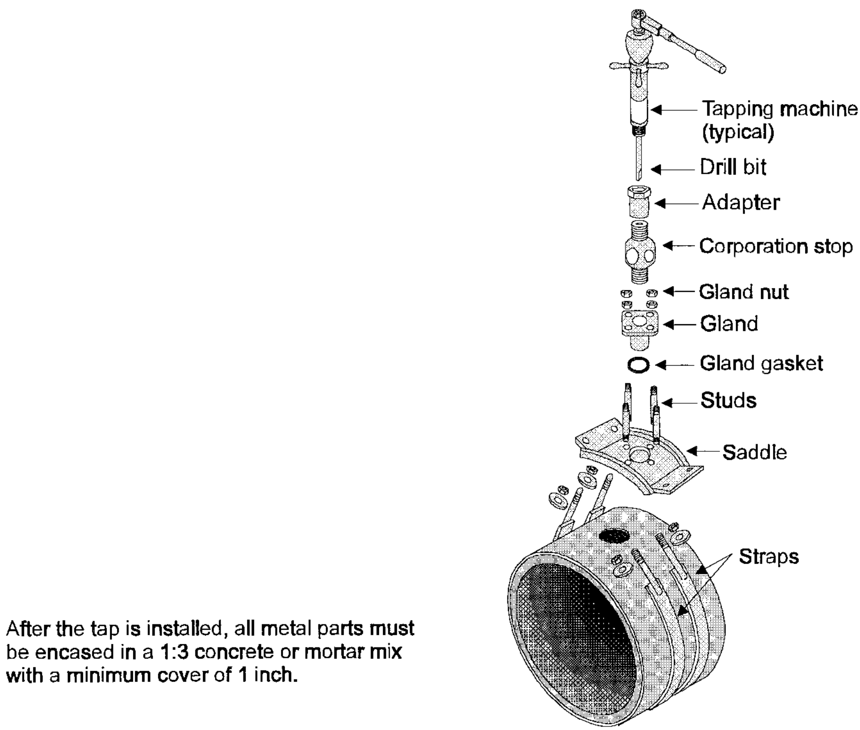

FIGURE A8.15 Strap-type tapping saddle assembly.

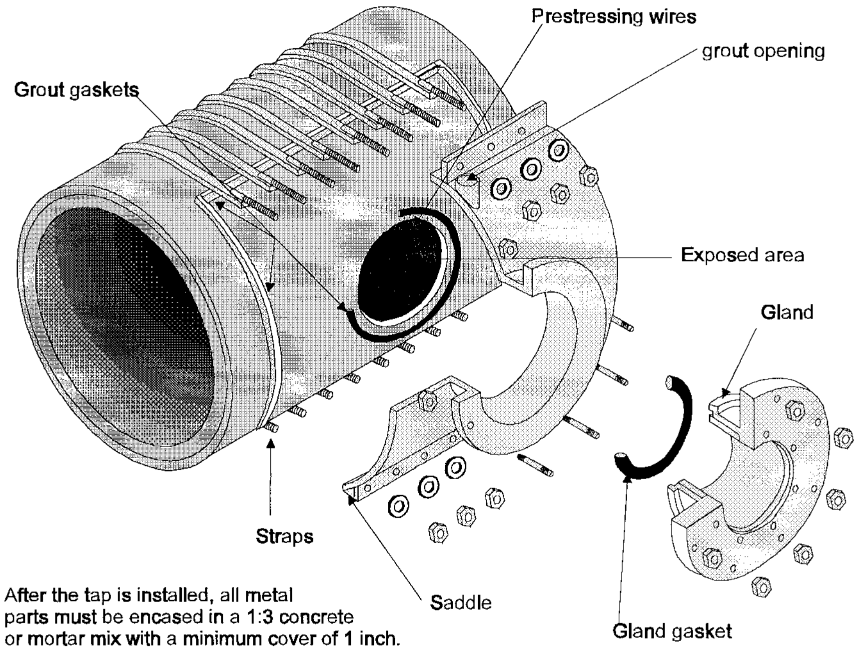

FIGURE A8.16 Flange-type tapping saddle assembly.

most cases, the tap can be done under pressure without interrupting service to customers. Tap diameters commonly range from NPS ¾ (DN 20) up to one size smaller than the pipe being tapped. For full size branch connections, a cut-in tee arrangement or a line stopping process may be feasible. The tapping saddle assembly used must be properly designed to work with PCCP. Figure A8.15 shows a strap-type tapping saddle assembly, and Fig. A8.16 shows a larger flange-type tapping saddle assembly. The strap-type saddle is normally used for tap diameters NPS ¾ (DN 20) to NPS 2 (DN 50). The flange-type saddle is used for tap diameters NPS 3 (DN 80) and larger. Consult the pipe manufacturer for additional information on tapping saddle assemblies and services provided.

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