CHAPTER B9

CEMENT MORTAR AND CONCRETE LININGS FOR PIPE

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INTRODUCTION

History

It has been known for over 100 years that portland cement mortar and concrete provide considerable protection to embedded ferrous materials against the corrosive effects of soil and water. The most common embedded ferrous material receiving this type of protection has been the steel bars in reinforced concrete. There are literally thousands of reinforced concrete bridges, buildings, parking garages, and other structures in service today. During the 1920s practical methods were developed to apply portland cement mortar linings to cast-iron and steel pipe in the manufacturing plant. In the 1930s a method for applying cement mortar linings to in-situ pipe was developed. Since that time, a significant amount of steel pipe, cast-iron pipe, and more recently, ductile iron pipe has been lined with portland cement mortar. Portland cement mortar linings have become the most common protective measure used for pipe in water and wastewater service. The concrete pressure pipe industry also took advantage of the protective properties of portland cement mortar and concrete during the development of reinforced concrete pressure pipe in the early 1900s and prestressed concrete pressure pipe in the early 1940s. Since the mid-1940s, portland cement mortar and concrete linings for concrete pressure pipe have proven highly successful, with almost all such pipe still remaining in active service. Portland cement mortar and concrete linings are very economical and provide superior corrosion protection.

Terminology and Definitions

Mortar	A mixture of portland cement, fine aggregate (sand), and water

Concrete	A mixture of portland cement, fine aggregate (sand), coarse aggregate (gravel), and water
Tuberculation	The formation of localized corrosion products scattered over the metal surface in the form of knoblike mounds
Passivation	The formation of a tightly adhering and protective chemical oxide film on the metal surface due to the presence of highly alkaline portland cement mortar or concrete
Vertical casting	A method of placing the concrete for a pipe involving the use of a steel inside form and outside form
Centrifugal casting	A method of placing a concrete or mortar lining by centrifugal force inside a revolving cylinder
Radial compaction	A vertical method of placing a pipe's concrete lining by the use of a special revolving packerhead
Pneumatic placement	A method of applying a mortar lining to a surface using compressed air equipment

Application

The interior of unprotected ferrous metal water pipelines can be attacked and damaged by corrosion, which in turn can lead to the formation of leaks, scale, or tuberculation or a combination of these defects. Leaks obviously compromise the structural integrity of the pipeline, resulting in the need for repair or replacement. The buildup of corrosion products in the form of scale or tuberculation can seriously degrade the flow characteristics of the pipeline. If the condition becomes severe enough, repair or replacement is required. For this reason, it is imperative that some form of protection be provided to the ferrous metal surface. Portland cement mortar and concrete protective linings have been found to be a highly effective and economical solution.

Reference Standards

Table B9.1 summarizes the commonly used industry standards which apply to portland cement mortar and concrete linings for pipe.

References

Table B9.2 lists American Water Works Association (AWWA) manuals that provide technical information and guidance for portland cement mortar- and concrete-lined pipe.

TABLE B9.1 Reference AWWA Standards for Cement Mortar and Concrete Linings for Pipe

Number	Title	Remarks
American National Standards Institute (ANSI)/ American Water Works Association (AWWA) C104/A21.4[1]	Standard for Cement-Mortar Lining for Ductile-Iron Pipe and Fittings for Water	For factory-applied mortar linings in ductile iron pipe
ANSI/AWWA C205[2]	Standard for Cement-Mortar Protective Lining and Coating for Steel Water Pipe-NPS 4 (DN 100) and Larger-Shop Applied	For factory-applied mortar linings in steel pipe
ANSI/AWWA C300[3]	Standard for Reinforced Concrete Pressure Pipe, Steel-Cylinder Type	For concrete and mortar linings in concrete pressure pipe
ANSI/AWWA C301[4]	Standard for Prestressed Concrete Pressure Pipe, Steel-Cylinder Type	For concrete and mortar linings in concrete pressure pipe
ANSI/AWWA C302[5]	Standard for Reinforced Concrete Pressure Pipe, Non-Cylinder Type	For concrete and mortar linings in concrete pressure pipe
ANSI/AWWA C303[6]	Standard for Concrete Pressure Pipe, Bar-Wrapped, Steel-Cylinder Type	For mortar linings in concrete pressure pipe
ANSI/AWWA C602[7]	Standard for Cement-Mortar Lining of Water Pipelines in Place-NPS 4 (DN 100) and Larger	For field-applied mortar linings in steel pipe, cast iron pipe, and ductile iron pipe

Corrosion-Preventative Properties of Portland Cement Mortar and Concrete for Lined or Encased Steel and Iron

Portland cement mortar or concrete linings protect steel and iron by three interrelated processes:

1. They form a barrier coating which works to prevent physical damage to the metal surface.
2. They passivate the metal surface. Hydrated portland cement is highly alkaline, with a pH of about 12.5. At that pH, a passivating oxide film forms and is maintained on the metal surface, preventing corrosion.

TABLE B9.2 Reference AWWA Manuals for Cement Mortar and Concrete Linings for Pipe

Title	Remarks
American Water Works Association Manual of Water Supply Practices "M9—Concrete Pressure Pipe"[8]	Covers the four types of concrete pressure pipe and fittings
American Water Works Association Manual of Water Supply Practices "M11—Steel Pipe–A Guide for Design and Installation"[9]	Covers steel pipe and fittings
American Water Works Association Manual of Water Supply Practices "M41—Ductile Iron Pipe and Fittings"[10]	Covers ductile iron pipe and fittings

3. Chemical reactions can occur in the mortar or concrete lining which can make infiltrating corrodants harmless, or they can form compounds that physically block further infiltration of corrodants.

Table B9.3 lists the types of fluids for which cement mortar and concrete linings are suitable and recommended.

TABLE B9.3 Transmitted Fluids for Which Cement Mortar and Concrete Linings Are Suitable

Transmitted fluid
Raw fresh water
Potable water
Raw sewage
Treated sewage
Seawater
Power plant cooling water (both seawater and fresh water)

CONCRETE PRESSURE PIPE AND FITTINGS

Pipe

Pipe manufactured in accordance with the ANSI/AWWA C300,[3] C301,[4] and C302[5] standards is required to have high-strength structural concrete on the inside surfaces of the pipe which, in addition to enhancing the load-carrying capability, provides corrosion protection to the embedded reinforcing elements. All concrete is placed at the factory by vertical casting, centrifugal casting, or radial compaction methods.

Pipe manufactured in accordance with the ANSI/AWWA C303[6] standard is

TABLE B9.4 Concrete Core and Mortar Lining Application and Curing Methods for Concrete Pressure Pipe

		ANSI/AWWA C300	ANSI/AWWA C301	ANSI/AWWA C302	ANSI/AWWA C303
Pipe	Application	Vertical casting or radial compaction, concrete mix temperature must be between 40°F (4°C) and 90°F (32°C)	Centrifugal casting, vertical casting, or radial compaction, concrete mix temperature must be between 40°F (4°C) and 90°F (32°C)	Vertical casting or radial compaction, concrete mix temperature must be between 40°F (4°C) and 90°F (32°C)	Centrifugal casting, concrete mix temperature must be over 40°F (4°C)
	Curing	Accelerated method with steam for 12 hrs minimum, or with water for 12 hrs minimum	Accelerated method with steam for 12 hrs minimum, or with water for 12 hrs minimum	Accelerated method with steam for 12 hrs minimum, or with water for 12 hrs minimum	Accelerated method with steam for 6 hrs minimum, or with water for 24 hrs minimum
Fittings	Application	Hand-placed or pneumatic placement	Hand-placed or pneumatic placement	Hand-placed or pneumatic placement	Centrifugal casting, hand-placed, or pneumatic placement
	Curing	Accelerated method with steam for 12 hrs minimum, with water for 12 hrs minimum, or curing compound per ASTM C309	Accelerated method with steam for 12 hrs minimum, with water for 24 hrs minimum, or curing compound per ASTM C309	Accelerated method with steam for 12 hrs minimum, with water for 12 hrs minimum, or curing compound per ASTM C309	Accelerated method with steam for 6 hrs minimum, with water for 24 hrs minimum, or curing compound per ASTM C309

required to have a mortar protective lining. The mortar is mixed using 1 part portland cement to 3 parts fine aggregate, with enough water added to obtain the necessary workability. The mortar lining is placed at the factory by the centrifugal casting method.

Fittings

The fabricated steel fittings for all four types of concrete pressure pipe (ANSI/AWWA C300,[3] C301,[4] C302,[5] and C303[6]) receive a mortar lining. The mortar is mixed using 1 part portland cement to 3 parts fine aggregate, with enough water added to obtain the necessary workability. These mortar linings are placed at the factory by hand layup, pneumatic placement, or centrifugal casting methods.

Application methods and curing

Table B9.4 summarizes the lining application and curing methods allowed by the various concrete pressure pipe standards. This table also shows the limits on the ambient temperature and the mortar or concrete mix temperature during application of the lining.

Thickness

The thickness of the concrete or mortar linings for concrete pressure pipe vary by pipe diameter and pipe type but are at least 0.50 in (13 mm) thick. In the case of the AWWA C300,[3] C301,[4] and C302[5] pipe, the concrete core, in addition to providing corrosion protection to the steel cylinder or reinforcing mesh, provides resistance to external loads. This is why the thickness can vary with the design parameters. The mortar lining in the AWWA C303[6] type of pipe is primarily used to provide corrosion protection to the steel cylinder. Its thickness does not generally change with the design parameters. The mortar lining for fittings of all concrete pressure pipe types must be at least 0.375 in (9 mm) thick. The primary purpose of the mortar lining in fittings is to provide corrosion protection.

Joint Protection

As shown in Fig. B9.1, a small annular gap between the lining of adjoining pipe sections results after assembly of a concrete pressure pipe steel bell and spigot joint in the field. Depending on the nature of the water being transported and the protective coating applied to the joint rings by the pipe manufacturer, it may be

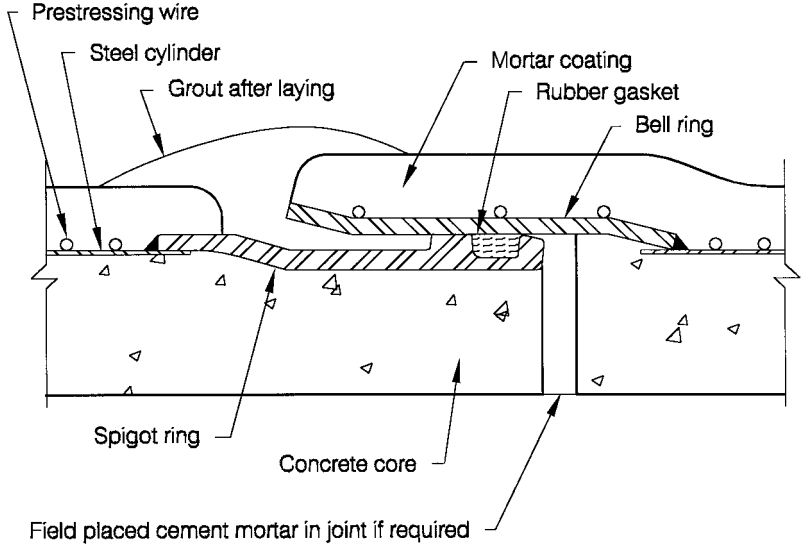

FIGURE B9.1 Mortaring of interior joint recess for prestressed concrete cylinder pipe.

necessary for the installing contractor to mortar this annular recess to protect the steel joint rings. The transmission of aggressive water such as raw sewage or seawater usually requires that the inside joint recess be filled with cement mortar after installation.

DUCTILE IRON PIPE AND FITTINGS

In most cases, ductile iron pipe and fittings are mortar-lined at the factory. Field application of a mortar lining is normally done on older, in-service pipe for rehabilitation purposes. Ductile iron pipe can be supplied with protective linings other than cement mortar lining. Some of the other protective linings may be more appropriate, depending upon the fluid being transported. For instance, ductile iron pipe transmitting raw sewage under gravity flow conditions might be lined with a protective material since sulfuric acid, which may form in the space above the flow, can severely attack portland cement mortar linings and ferrous pipe materials. For most nonaggressive raw water and potable water transmission situations, cement mortar linings are very economical and the most common means of protection.

Table B9.5 summarizes the mortar lining application methods, curing methods, and mix proportions used in the manufacturing plant and in the field for ductile

TABLE B9.5 Cement Mortar Lining Application, Curing, and Mix Proportions for Ductile Iron Pipe

		Applied at manufacturing plant	Applied in the field
Pipe	Application	Centrifugal casting or pneumatic placement	Mechanical placement and troweling
	Curing	Asphaltic seal coat, steam, or water	Water
	Mix proportions	1 part portland cement, not more than 2 parts fine aggregate, and sufficient water to achieve required workability	1 part portland cement to 1–1½ parts fine aggregate, and sufficient water to achieve required workability
Fittings	Application	Hand-placed or pneumatic placement	Hand-placed if not by mechanical placement and troweling
	Curing	Asphaltic seal coat, steam, or water	Water
	Mix proportions	1 part portland cement, not more than 2 parts fine aggregate, and sufficient water to achieve required workability	1 part portland cement to 1–1½ parts fine aggregate, and sufficient water to achieve required workability

TABLE B9.6 Factory-Applied Mortar Lining Thickness for Ductile Iron Pipe and Fittings

Pipe size range	Mortar lining thickness
NPS 3–NPS 12 (DN 75–DN 300)	0.0625 in (1.6 mm)
NPS 14–NPS 24 (DN 350–DN 600)	0.0938 in (2.4 mm)
NPS 30–NPS 64 (DN 750–DN 1600)	0.125 in (3.2 mm)

iron pipe and fittings. Table B9.6 summarizes the factory-applied mortar lining thickness requirements for ductile iron pipe and fittings. Linings with twice the thicknesses shown in Table B9.6 (known as double thickness) can be supplied for extra protection if requested by the purchaser. Table B9.7 shows the field-applied mortar lining thickness requirements for ductile iron pipe and fittings.

TABLE B9.7 Field-Applied Mortar Lining Thickness for Ductile Iron Pipe and Fittings

Pipe size range	Mortar lining thickness for old and new ductile iron
4–10 in (100–250 mm)	0.1875 in (4.8 mm)
11–23 in (280–580 mm)	0.25 in (6.4 mm)
24–36 in (600–900 mm)	0.3125 in (8 mm)
>36 in (900 mm)	0.3125 in (8 mm)

Joint Protection

As with the concrete pressure pipe joint, in the case of factory-applied mortar linings, a small annular gap between the lining of adjoining pipe sections results after assembly of a ductile iron bell and spigot joint in the field. Depending on the nature of the water being transported and the protective coating applied to the joint surfaces by the pipe manufacturer, it may be necessary for the installing contractor to mortar this annular recess to protect the joint. In the case of field-applied mortar lining, the lining is continuous across the joint, and no further work is needed at the joint.

STEEL PIPE AND FITTINGS

The decision regarding where to apply the mortar lining for steel pipe—at the manufacturing plant or in the field—is based on a number of factors including

TABLE B9.8 Cement Mortar Lining Application, Curing, and Mix Proportions for Steel Pipe and Fittings

		Applied at manufacturing plant	Applied in the field
Pipe	Application	Centrifugal casting	Mechanical placement and troweling
	Curing	Steam or water	Water
	Mix proportions	1 part portland cement, not more than 3 parts fine aggregate, and sufficient water to achieve required workability	1 part portland cement to 1–1½ parts fine aggregate, and sufficient water to achieve required workability
Fittings	Application	Hand-placed or pneumatic placement if not by centrifugal casting	Hand-placed if not by mechanical placement and troweling
	Curing	Steam or water	Water
	Mix proportions	1 part portland cement, not more than 3 parts fine aggregate, and sufficient water to achieve required workability	1 part portland cement to 1–1½ parts fine aggregate, and sufficient water to achieve required workability

manufacturer capabilities, pipe diameter, shipping and handling considerations, and field installation conditions. As with ductile iron pipe, steel pipe can be supplied with a range of linings, only one of which is cement mortar lining.

Table B9.8 summarizes the mortar lining application methods, curing methods, and mix proportions used in the manufacturing plant and in the field for lining steel pipe and fittings. Table B9.9 shows the factory-applied mortar lining thickness requirements for steel pipe and fittings. Table B9.10 shows the typical field-applied mortar lining thickness requirements for steel pipe and fittings.

TABLE B9.9 Factory-Applied Mortar Lining Thickness for Steel Pipe and Fittings

Pipe size range	Mortar lining thickness
4–10 in (100–250 mm)	0.25 in (6 mm)
11–23 in (280–580 mm)	0.3125 in (8 mm)
24–36 in (600–900 mm)	0.375 in (10 mm)
>36 in (900 mm)	0.50 in (13 mm)

TABLE B9.10 Field-Applied Mortar Lining Thickness for Steel Pipe and Fittings

Pipe size range	Mortar lining thickness for old steel	Mortar lining thickness for new steel
4–10 in (100–250 mm)	0.3125 in (8 mm)	0.25 in (6 mm)
11–23 in (280–580 mm)	0.375 in (10 mm)	0.3125 in (8 mm)
24–36 in (600–900 mm)	0.4375 in (11 mm)	0.375 in (10 mm)
>36 in (900 mm)	0.5625 in (14 mm)	0.50 in (13 mm)

Joint Protection

In the case of factory-applied mortar linings, it is necessary for the contractor to mortar the inside gap at the joints after installation. Field-welded joints, for instance, will have had the mortar lining held back a few inches at each end to avoid damage due to welding. Figure B9.2 illustrates this example showing a steel pipe lap-welded slip joint. The installing contractor must hand-place the mortar to these uncoated surfaces after welding. This mortar shall be mixed using 1 part portland cement to not more than 3 parts fine aggregate by weight. Use only enough water to obtain the required workability. In the case of field-applied mortar lining, the lining is continuous across the joint, and no further work is needed at the joint.

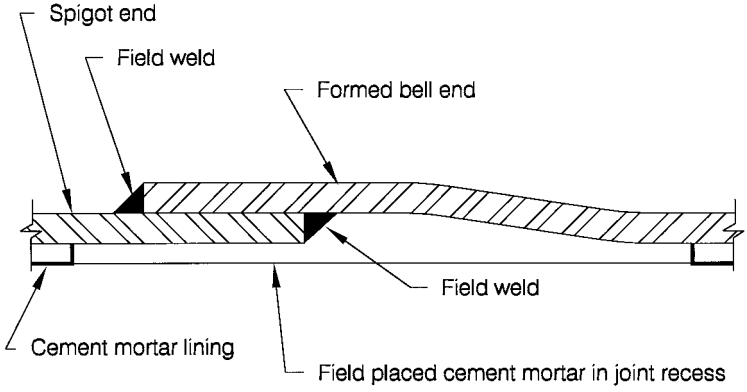

FIGURE B9.2 Mortaring of interior joint recess for field-welded lap joint steel pipe.

MISCELLANEOUS CONSIDERATIONS

Supplemental Protection for Concrete and Mortar Linings

There are some service conditions which can be aggressive to concrete and mortar linings. Two of the most common are:

- Raw sewage: In sewer lines that do not flow full, under certain conditions hydrogen sulfide gas can be generated by biological action in the flow area and then be discharged into the air space above the flow line. In the environment above the flow line, bacteria and moisture can convert this hydrogen sulfide gas to sulfuric acid, which will attack concrete and mortar linings.
- Soft water: Soft water (water with very low calcium carbonate hardness) may attack concrete and mortar linings by leaching minerals from the cement matrix.

If these conditions are expected to occur in the pipe, steps should be taken to protect the concrete or mortar lining or to use another lining that is resistant to these conditions. The pipe manufacturer should be consulted for specific recommendations and availability of supplemental protective measures.

Inspection and Repair

After pipe has left the factory, the mortar or concrete lining may be subject to minor shrinkage cracking, especially in low humidity conditions. The existence of this type of cracking usually does not indicate any structural distress. Once the pipe has been filled with water, the shrinkage process will reverse and minor cracks will close. All pipe and fittings should be carefully inspected upon their arrival on the jobsite. Damaged, loose, or severely cracked concrete or mortar lining should be noted at this time and evaluated for repair. The pipe manufacturer should be consulted for assistance in evaluation and for repair procedures.

Shipping and Handling

Care should always be exercised when lifting and handling concrete- or mortar-lined pipe. Wire rope lifting cables should never be placed through the pipe or fitting and allowed to bear directly against the lining. Any lifting device that bears against the concrete or mortar lining must be suitably padded to avoid damage.

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