8.3.6 Geosynthetics. Geosynthetics, including geotextiles and geocomposites, by their nature do not have to be designed for structural strength to carry live loads or dead loads. These systems, however, should be designed for possible shear forces from installation and construction operations. They should have sufficient strength to prevent tearing during installation and construction activities. Koerner (2005) discusses "survivability" requirements for geotextiles (Koerner, 2005, Sections 2.1.2 and 2.11.2). Similar considerations apply to geocomposites.

8.4 PIPE APPURTENANCES AND OTHER STRUCTURES

8.4.1 Pipe Appurtenances. Closed conduits within the pipe category, other than conduit-like products used as drop structures, generally will be used as surface discharge components of the surface water collector or conduit system. As such, pipes and appurtenances (valves, couplings, etc.) will have similar structural, hydraulic, and corrosion protection needs as the same materials applied to surface drainage systems. Additionally, extra care is required to prevent the admittance of rubbish and debris into the pipe components (or to allow them to freely flow through) and to provide adequate protection against degradation that may occur from direct exposure to chemicals—such as fuels and oils—or particulate abrasion by solids carried by the stormwater.

8.4.2 Other Structures. Stormwater collection in urban environments mainly involves the interception of water flowing across both natural and vegetated soils or paved surfaces. The interceptor or collector can serve either as a detention/retention device or incorporate an outlet for discharging the water and conveying it to another type of system, such as a storm sewer or basin.

A common example of a surface water interceptor is the curb inlet. Curb inlets rely on the curb to direct water toward the opening, essentially establishing the characteristics of channel flow. Because these are at or near street or ground elevations, the primary structural concerns relate to the imposition of live loads from vehicles that will both impact and run over the structure. Secondary concerns relate to scour, impact forces due to debris within the runoff, and possible degradation due to chemical exposure. As such, concrete box construction and removable cast steel or iron tops have proven to be the most durable and cost-efficient.

The collection of sheet flow across relatively impervious surfaces, in the absence of curbs or other construction to direct and concentrate flow, generally involves providing a surface opening that runs perpendicular to the direction of runoff. The opening is relatively long and narrow, creating a slot into which runoff water drops from the surface into a larger collector. The collector is usually circular, such as a pipe, or a semicircular trough-like structure.

These products, usually prefabricated for on-site assembly, are manufactured from steel or high-strength nonmetallic material (such as fiberglass) or both and are installed at very shallow depths. As such, the dominant structure consideration concerns live loads, generally from motor vehicles. The inlet structures should be very durable, given their usual direct exposure to traffic. These slotted-drain-type structures normally are installed in excavated trenches and backfilled with concrete to ensure stability.

Structural requirements for open-channel linings and open-channel structures are discussed in 7.3.6.

CHAPTER 9
MATERIALS

This section is intended to provide general information on pipe, culvert, and other materials used in surface drainage applications.

In many cases, several pipe types may be satisfactory for a particular installation. When appropriate, pipe should conform to the requirements of ASTM International (ASTM), the American Association of State Highway and Transportation Officials (AASHTO), or another recognized standard-setting organization. A separate metric edition of a standard may be available in some cases. If so, it is designated by the letter "M" following the specification number. Typically installation requirements are not included as part of the product specifications and must be determined by the engineer and included in the construction contract documents.

With the wide variety of materials in use today, field connections between different pipe are common. Regulations may stipulate that a structure, such as a manhole, be placed at these junctions, especially if there will be a change in pipe size, grade, or direction. However, other alternatives also may be successful. One common alternative is to butt the two pipe ends together and pour a nonshrink concrete grout around them. Special fittings and adapters are available that in many cases can make the transition between different products. Many provide very tight, flexible connections. Pipe manufacturers are an excellent source of information for what types of transition fittings will work.

Some surface drainage systems do not require watertight connections. Many of the products listed in the following sections, however, may be available with joints that are watertight to varying degrees. When not stated within the specification, contact the manufacturer for more information regarding specific joint quality.

The following list of standards is for products commonly accepted for surface drainage projects. It is not the intent of this list to restrict the use of other products that may be satisfactory.

9.1 ENVIRONMENTAL CONSIDERATIONS

Some pipe materials may exhibit reduced life in aggressive environments containing corrosive chemicals, abrasives, or electrically "hot" soils. Options, such as polymer or asphalt linings, are available for many concrete and steel pipes to increase the life of the system in such environments. If potentially aggressive conditions are present, the pipe manufacturer should be contacted for any necessary precautions and assurance that the precaution will provide service life requirements.

In some areas where receiving waters are sensitive to heavy metals, such as zinc, the use of galvanized pipe products may be discouraged or prohibited. In that case, aluminized or steel reinforced plastic pipe may be appropriate.

9.2 ECONOMIC CONSIDERATIONS

Economic considerations should be made on the basis of the entire service life of the drainage system. Considerations should include material, equipment, and labor costs; rates of installation; system maintenance and replacement; and costs associated with public inconveniences that may vary among material options.

9.3 PIPE AND CULVERT MATERIALS

9.3.1 Rigid Pipe

9.3.1.1 Concrete Pipe. Reinforced and nonreinforced concrete pipes are used for gravity flow systems. Concrete fittings and appurtenances, such as wyes, tees, and manhole sections, are generally available. A number of jointing methods are available depending on the tightness required. Concrete pipe is specified by diameter, type of joint, and D-load strength or reinforcement requirements. The product should be manufactured in accordance with one or more of the following standard specifications:

ASTM C14/C14M: *Nonreinforced Concrete Sewer, Storm Drain, and Culvert Pipe.*

ASTM C76/C76M/AASHTO M170/M170M: *Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe*—covers reinforced concrete pipe intended to be used for the conveyance of sewage, industrial wastes, and stormwater.

ASTM C118/C118M: *Concrete Pipe for Irrigation or Drainage*—covers concrete pipe intended to be used for the conveyance of water with specified working pressures including hydraulic transients.

ASTM C361/C361M: *Reinforced Concrete Low-Head Pressure Pipe*—covers reinforced concrete pipe conduits with low internal hydrostatic heads generally not exceeding 125 ft (375 kPa).

ASTM C412/C412M/AASHTO M178/M178M: *Concrete Drain Tile*—covers concrete drain tile with internal diameters from 4 to 36 in. (100 to 900 mm).

ASTM C444/C444M/AASHTO M175/ M175M: *Perforated Concrete Pipe*—covers perforated concrete pipe intended to be used for underdrainage.

ASTM C478/C478M: *Precast Reinforced Concrete Manhole Sections*—covers products used for the assembly and construction of circular vertical precast reinforced concrete manholes and structures used in sewer, drainage, and water works.

ASTM C505/ C505M: *Nonreinforced Concrete Irrigation Pipe with Rubber Gasket Joints*—covers pipe to be used for the conveyance of water with specified working pressures.

ASTM C506/C506M/AASHTO M206/M206M: *Reinforced Concrete Arch Culvert, Storm Drain, and Sewer Pipe*—covers reinforced concrete arch-shaped concrete pipe to be used for the conveyance of sewage, industrial wastes, storm water, and the construction of culverts.

ASTM C507/C507M/AASHTO M207/M207M: *Reinforced Concrete Elliptical Culvert, Storm Drain, and Sewer Pipe*—covers reinforced elliptical concrete pipe to be used for the conveyance of sewage, industrial wastes, storm water, and the construction of culverts.

ASTM C654/C654M/AASHTO M176/M176M: *Porous Concrete Pipe*—covers porous nonreinforced concrete pipe for use in underdrains.

ASTM C655/C655M/AASHTO M242/M242M: *Reinforced Concrete D-Load Culvert, Storm Drain and Sewer Pipe*—covers reinforced concrete pipe for specific D-loads and intended to be used for the conveyance of sewage, industrial wastes, and stormwater.

ASTM C985/ C985M: *Nonreinforced Concrete Specified Strength Culvert, Storm Drain, and Sewer Pipe*—covers nonreinforced concrete pipe designed for specified strengths.

9.3.2 Metal Pipe. Corrugated metal pipe is fabricated from corrugated steel, aluminized steel, or aluminum sheets or coils. Corrugated metal pipe is specified by size, shape, wall profile, gauge or wall thickness, and coating or lining. Appurtenances, including tees, wyes, elbows, and manholes, are available. Corrugated metal pipe is limited to gravity flow applications. Corrugated metal pipe should be manufactured in accordance with one or more of the following standard specifications.

AASHTO M190: *Bituminous Coated Corrugated Metal Culvert Pipe and Pipe*—covers bituminous-coated corrugated metal pipe and pipe arches intended to be used for the construction of metal culverts of the following types: Fully Bituminous-Coated, Half Bituminous-Coated with Paved-Invert, Fully Bituminous-Coated and Paved-Invert, Fully Bituminous-Coated and 100 Percent Paved or Lined.

AASHTO M219: *Corrugated Aluminum Alloy Structural Plate for Field-Bolted Pipe, Pipe-Arches, and Arches*—covers corrugated aluminum alloy structural plate used in the construction of pipe, pipe-arches, arches, underpasses, and special shapes for field assembly.

AASHTO M274: *Steel Sheet, Aluminum-Coated (Type 2), for Corrugated Steel Pipe*—covers steel sheet used in the fabrication of corrugated steel pipe used for drainage pipe and underdrains. The steel sheet is coated with commercially pure aluminum (referred to as Type 2) on continuous lines by the hot-dip process.

ASTM A760/A760M/AASHTO M36: *Corrugated Steel Pipe, Metallic-Coated for Sewers and Drains*—covers metallic-coated corrugated steel pipe from 4- to 144-inch (100- to 3,600-mm) diameters.

ASTM A761/A761M/AASHTO M167/M167M: *Corrugated Steel Structural Plate, Zinc-Coated, for Field-Bolted Pipe, Pipe Arches, and Arches*—covers corrugated steel structural plate, zinc-coated, used in the construction of pipe and other shapes for field assembly.

ASTM A762/A762M/AASHTO M245: *Corrugated Steel Pipe, Polymer Precoated for Sewers and Drains*—covers polymer precoated corrugated steel pipe from 4 to 144 in. (100 to 3,600 mm) diameters.

ASTM A849: *Post-Applied Coatings, Pavings, and Linings for Corrugated Steel Sewer and Drainage Pipe*—covers post-applied coatings, pavings, and linings for corrugated steel pipe and corrugated steel structural plate pipe, pipe-arches, and arches coated, paved, or lined with specified materials over either metallic coatings or metallic coatings with polymer coatings.

ASTM A978/A978M, *Composite Ribbed Steel Pipe, Precoated and Polyethylene Lined for Gravity Flow Sanitary Sewers, Storm Sewers, and Other Special Applications*—covers composite ribbed steel pipe, precoated and polyethylene lined intended for use for gravity flow sanitary sewers, storm sewers, and other special applications where extra corrosion and abrasion resistance are required.

ASTM B745/B745M/AASHTO M196: *Corrugated Aluminum Pipe for Sewers and Drains*—covers corrugated aluminum pipe intended for use for storm water drainage, underdrains, the construction of culverts, and similar uses.

ASTM B746/B746M: *Corrugated Aluminum Alloy Structural Plate for Field-Bolted Pipe, Pipe-Arches, and Arches*—covers corrugated aluminum alloy structural plate used in the construction of pipe, pipe-arches, arches, underpasses, box culverts, and special shapes for field assembly.

9.3.3 Thermoplastic Pipe. Thermoplastic pipe materials include a broad variety of plastics that can be repeatedly softened by heating and hardened by cooling through a temperature range characteristic for each specific plastic, and in the softened state can be shaped by molding or extrusion. Generally, thermoplastic pipe materials are limited to acrylonitrile-butadiene-styrene (ABS), polyethylene (PE), and polyvinyl chloride (PVC). Thermoplastic pipes are produced in a variety of shapes and dimensions. Pipe properties can be modified by changing the wall thickness or profile, for both pressure and nonpressure applications.

9.3.3.1 Acrylonitrile-Butadiene-Styrene (ABS) Pipe. Acrylonitrile-Butadiene-Styrene (ABS) pipe is manufactured by extrusion of ABS material and is limited to gravity flow applications. ABS composite pipe is manufactured by extrusion of ABS material with a series of truss annuli that are filled with filler material such as lightweight Portland cement concrete. ABS fittings are available for the product. The jointing systems available include elastomeric gasket joints and solvent cement joints.

Gravity Flow Applications ABS pipe should be manufactured in accordance with one of the following standard specifications.

ASTM D2680/AASHTO M264: *Acrylonitrile-Butadiene-Styrene (ABS) and Poly(Vinyl Chloride) (PVC) Composite Sewer Piping*—covers ABS or PVC composite pipe, fittings, and a joining system for nonpressure systems.

ASTM D2751: *Acrylonitrile-Butadiene-Styrene (ABS) Sewer Pipe and Fittings*—covers ABS pipe and fittings from 3 to 12 in. (75 to 300 mm) diameter.

9.3.3.2 Polyethylene (PE) Pipe. PE pipe is used for both gravity and pressure flow systems. PE pipe is manufactured by extrusion of PE plastic material. PE refers to the base compound whereas finished polymers may be referred to as LLDPE (linear low density polyethylene) or HDPE (high density polyethylene). PE pipe is specified by material designation, nominal diameter (inside or outside), standard dimension ratios, ring stiffness, and type of joint. Hybrid products, such as steel reinforced polyethylene pipe (SRPE), are available when higher stiffness is needed for large diameter applications. PE fittings are available as well as butt fusion welding.

Gravity Flow Applications PE pipe for gravity flow applications should be manufactured in accordance with one or more of the following standard specifications.

ASTM F405: *Corrugated Polyethylene (PE) Pipe and Fittings*—covers pipe from 3 to 6 in. (75 to 150 mm) diameters.

AASHTO M252: *Corrugated Polyethylene Drainage Pipe*—covers pipe from 3 to 10 in. (75 to 250 mm) diameters.

ASTM F667: *Large Diameter Corrugated Polyethylene Pipe and Fittings*—ASTM F667 covers pipe from 8 to 24 in. (203 to 610 mm) diameters.

AASHTO M294: *Corrugated Polyethylene Pipe 300 to 1500 mm (12 to 60 in.).*

ASTM F810: *Smoothwall Polyethylene (PE) Pipe for Use in Drainage and Waste Disposal Absorption Fields*—covers smoothwall PE pipe, including coextruded, perforated, and nonperforated from 3 to 6 in. (75 to 150 mm) diameters.

ASTM F894: *Polyethylene (PE) Large Diameter Profile Wall Sewer and Drain Pipe*—covers profile wall PE pipe from 10 to 120 in. (250 to 3,050 mm) diameters for gravity flow applications.

AASHTO MP 20-10: *Steel-Reinforced Polyethylene (PE) Ribbed Pipe, 300 to 900 mm (12 to 36 in.) Diameter*—covers a class of pipe containing steel reinforcing rods that are molded into the pipe ribs. This imparts higher strength and allows the pipe to be design as nonflexible, especially for larger diameters.

ASTM F2562/F2562M: *Steel Reinforced Thermoplastic Ribbed Pipe and Fittings for Non-Pressure Drainage and Sewerage*—covers steel reinforced thermoplastic pipe and fittings of nominal sizes 8 in. (200 mm) through 120 in. (3,000 mm), intended for use in underground applications where soil provides support for their flexible walls, used for gravity flow and non-pressure applications such as storm sewers, drainage pipes, and others.

Pressure Flow Applications PE pressure pipe should be manufactured in accordance with one or more of the following standard specifications.

ASTM D2239: *Polyethylene (PE) Plastic Pipe (SIDR-PR) Based on Controlled Inside Diameter*—covers PE pipe made in standard thermoplastic pipe dimensions and pressure rated for water.

ASTM D3035: *Polyethylene (PE) Plastic Pipe (DP-PR) Based on Controlled Outside Diameter*—covers PE pipe made in standards thermoplastic pipe dimensions based on outside diameter and pressure rated for water.

9.3.3.3 Polyvinyl Chloride (PVC) Pipe. PVC pipe is used for both gravity and pressure flow systems. PVC pipe is manufactured by extrusion of the material. Higher strength PVC composite pipe is manufactured by extrusion of PVC material with a series of truss annuli that are filled with material, such as lightweight Portland cement concrete. PVC pipe is specified by nominal diameter, dimension ratio, pipe stiffness, and type of joint. PVC pressure and nonpressure fittings are available. Joints are typically solvent welded or gasketed depending on the application and diameter.

Gravity Flow Applications PVC pipe for gravity flow applications should be manufactured in accordance with one or more of the following standard specifications.

AASHTO M304: *Poly(Vinyl Chloride) (PVC) Profile Wall Drain Pipe and Fittings Based on Controlled Inside Diameter*—covers Poly(Vinyl Chloride) (PVC) profile wall perforated and nonperforated pipe and fittings, 100 to 1200 mm (4 to 48 in.) nominal inside diameter, for use in nonpressure storm drains, culverts, underdrains, and other subsurface drainage systems providing either soil-tight or watertight joints.

ASTM D2680/AASHTO M264: *Acrylonitrile- Butadiene-Styrene (ABS) and Poly(Vinyl Chloride) (PVC) Composite Sewer Piping*—covers ABS or PVC composite pipe, fittings, and a joining system for nonpressure sanitary sewer and storm drain systems.

ASTM D2729: *Poly(Vinyl Chloride) (PVC) Sewer Pipe and Fittings*—covers material and test requirements for PVC pipe and fittings for sewer and drain pipe. Standard perforations available only in 4 in. (100 mm) diameter pipe.

ASTM D3034: *Type PSM Poly(Vinyl Chloride) (PVC) Sewer Pipe and Fittings*—covers material and test requirements for PVC pipe and fittings for sewer pipe systems.

ASTM F679: *Poly(Vinyl Chloride) (PVC) Large-Diameter Plastic Gravity Sewer Pipe and Fittings*—covers material and test requirements for PVC gravity sewer pipe and fittings from 18 to 48 in. (450 to 1,200 mm) diameters, with integral bell elastomeric seal joints and smooth inner walls.

ASTM F758: *Smooth-Wall Poly (Vinyl Chloride) (PVC) Plastic Underdrain Systems for Highway, Airport, and Similar Drainage*—covers material and test requirements for smooth wall pipe and fittings for PVC underdrains from 4 to 8 in. (100 to 200 mm) diameters with perforated or nonperforated walls for use in subsurface drainage systems.

ASTM F794: *Poly(Vinyl Chloride) (PVC) Profile Gravity Sewer Pipe and Fittings Based on Controlled Inside Diameter*—covers materials and test requirements for PVC gravity sewer profile pipe and fittings, with integral bell and elastomeric seal joints.

ASTM F949: *Poly(Vinyl Chloride) (PVC) Corrugated Sewer Pipe with a Smooth Interior and Fittings*—covers materials and test requirements for PVC pipe and fittings from 4 to 48 in. (100 to 1,200 mm) diameters with corrugated outer wall fused to a smooth inner wall for sanitary and storm sewers and perforated and nonperforated pipe for subdrainage.

Pressure Flow Applications PVC pressure pipe should be manufactured in accordance with one of the following standard specifications.

ASTM D1785: *Poly(Vinyl Chloride) (PVC) Plastic Pipe, Schedules 40, 80, 120*—covers materials and test requirements for PVC pipe pressure rated for use with the distribution of pressurized liquids.

ASTM D2241: *Poly(Vinyl Chloride) (PVC) Pressure Rated-Pipe (SDR Series)*—covers materials and test requirements for PVC pipe pressure rated for water.

ANSI/AWWA C900: *Poly-vinyl Chloride (PVC) Pressure Pipe and Fabricated Fittings, 4 in through 12 in.* (100 *mm through 300 mm), for Water Transmission and Distribution*—covers materials and test requirements for PVC pipe pressure rated for water.

ANSI/AWWA C905: *Poly-vinyl Chloride (PVC) Pressure Pipe and Fabricated Fittings, 14-in. through 48 in. (350 through 1200 mm), for Water Transmission and Distribution*—covers materials and test requirements for PVC pipe pressure rated for water transmission in sizes ranging from 14 to 48 in. (350 to 1,200 mm) outside diameters, and dimension ratios (DRs) of 14, 18, 21, 25, 26, 32.5, 41, and 51.

9.3.4 Box Culverts

9.3.4.1 Reinforced Concrete Box Culverts, Precast. Boxes may be manufactured using conventional structural concrete and forms or with dry concrete and vibrating form pipe-making methods. The product should be manufactured in accordance with one of the following specifications.

AASHTO M259/M259M: *Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers*—covers single-cell precast reinforced concrete box sections with less than 2 ft (0.6 m) of earth cover when subjected to highway loads.

AASHTO M273/M273M: *Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers with Less Than 2 Feet (0.6 m) of Cover Subjected to Highway Loading*—covers box sections with less than 2 ft (0.6 m) of earth cover subjected to highway loading and intended to be used for the construction of culverts and the conveyance of stormwater, industrial wastes, and sewage.

ASTM C1433/C1433M: *Precast Reinforced Concrete Monolithic Box Sections for Culverts, Storm Drains, and Sewers*—covers single-cell precast reinforced concrete box sections cast monolithically and proposed for use in the construction of culverts and for the conveyance of stormwater, industrial wastes, and sewage.

ASTM C1577: *Standard Specification for Precast Reinforced Concrete Monolithic Box Sections for Culverts, Storm Drains, and Sewers Designed According to AASHTO LRFD*—covers single-cell precast reinforced concrete box sections cast monolithically and intended to be used for the construction of culverts and for the conveyance of storm water, industrial wastes, and sewage.

ASTM C1677: *Standard Specification for Joints for Concrete Box, Using Rubber Gaskets*—covers flexible joints for concrete box sections, using rubber gaskets for leak resistant joints. The specification covers the design of joints and the requirements for rubber gaskets to be used therewith, for boxes conforming in all other respects to Specification C1433 or C1577, provided that if there is conflict in permissible variations in dimensions the requirements of this specification for joints shall govern.

9.3.4.2 Structural Plate Box Culverts. Structural plate box culverts are composite reinforcing rib-plate structures made of aluminum or steel. Reinforcing ribs are a curved structural section bolted to a structural plate. The product should be manufactured in accordance with one of the following specifications.

ASTM A964/A964M: *Standard Specification for Corrugated Steel Box Culverts*—covers material, geometric, and wall section properties of steel box culverts manufactured from corrugated plate or sheet, with or without attached stiffeners, for field assembly.

9.3.5 Pipe Joints. Pipe joint quality should be specified in the contract documents based on the needs of the project.

9.4 OTHER MATERIALS AND PRODUCTS

Some national standard specifications for geocomposites, geonets, geomembranes, geotextiles, aggregates, and wick drains (also called chimney or vertical strip drains) are listed in *Standard Guidelines for the Design of Urban Subsurface Drainage* (ASCE 2013). There are numerous additional standards for geomembranes and geotextiles, for which the reader can refer to the standards organizations.

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CHAPTER 10
REGULATIONS AND PERMITS

During the conceptual stages of an urban stormwater drainage project, it is important to obtain copies and to have an understanding of all applicable federal, state, and local codes. At the same time, all federal, state, and local permits for the project should be identified with the requirements of each permit clearly understood, including submittal timing. It is very important to consider the coordination of permits to ensure compliance with all requirements and to avoid potential conflicts and project delays.

10.1 REGULATIONS

10.1.1 Urban Stormwater Systems. Federal, state, and local codes that apply to the design and operation of an urban stormwater system should be considered.

10.1.2 Urban Surface Drainage Systems. Federal, state, and local codes that apply to the construction of an urban surface drainage system should be considered.

10.2 PERMITS

Federal, state, and local temporary permits, which are necessary prior to and during construction of an urban stormwater or surface drainage project, should be secured by the owner, owner's agent, or contractor prior to construction. Any permanent permits, such as the Corps of Engineers' permit—which must be maintained after construction of the project—should be secured by the owner or the owner's agent.

10.2.1 Contract Documents. A copy of all temporary and permanent permits secured by the owner or owner's agent for the project should be included as part of the contract documents. Copies of all permits secured by the owner's agent or the contractor should be furnished to the owner.

10.2.2 Terms and Provisions. The contractor is responsible to conform to the terms and provisions of all permits required during construction as stated in the contract documents.

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CHAPTER 11
REFERENCES

11.1 CITED REFERENCES

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