Chapter 4 - Products & Applications

4.1 Products

Corrugated HDPE and PP pipe products, collectively referred to as corrugated plastic pipes (CPP), have largely evolved as a result of market demands and manufacturing technology. Since they are produced from versatile materials, CPP are used in a broad array of drainage applications.

4.1.1 Single-wall Corrugated HDPE Pipe

Single-wall corrugated HDPE pipe has a corrugated exterior and interior. This type of pipe is used for drainage projects in which flexibility, light weight, and low cost are important. Single-wall corrugated HDPE is produced in accordance with a number of national specifications, which include ASTM F667, AASHTO M 252 (3 to 10-in. (7.6 to 25 cm)) diameter, and AASHTO M 294 (larger than 10-in. (25 cm) diameter). Pipe diameters range in size from 3 to 24 in. (7.6 to 60 cm), however larger diameters of single-wall can be made. Single-wall may be manufactured in 10-ft (3-m) lengths, more commonly-used 20 ft (6-m) lengths, and continuous lengths greater than 5000 ft (1524 m), depending on the diameter. The specific design of the pipe varies by manufacturer, and individual pipe manufacturers should be consulted regarding for available lengths and diameters. Figure 4.1 shows an example of a type of single-wall corrugated HDPE pipe.

Figure 4.1: Single-wall HDPE pipe

Specific applications for single-wall HDPE pipe include, but are not limited to, the following:

- Agricultural drainage;
- Drain fields and French drains;
- Landscape drainage and sub-drainage;
- Slope, edge, and foundations;
- Downspouts and roof drainage;
- Pavement edge drains and underdrains;
- Golf courses;
- Athletic fields;
- Grain aeration;
- Land reclamation; and,
- Toe drains.

For subsurface water collection or leaching action, single-wall corrugated HDPE pipe is available with slots or drilled hole perforations. Perforated single-wall pipe may be supplied with a geotextile wrap, which is often recommended for projects involving fine sand, soil, or flowable particles of soil. Perforated single-wall HDPE pipe is also used for highway edge drains, culverts, and other construction applications where economy and durability are important.

Non–perforated pipe is used when water must be conveyed by gravity flow from one point to another. Single-wall corrugated pipe has been successful at helping to keep farms, golf courses, parks, and playing fields dry for decades by channeling away excess underground moisture.

Homeowners also commonly use single-wall HDPE because it is an economical, easy-to–install solution to all kinds of residential stormwater drainage problems, such as downspouts run offs, foundation drainage, window well drains, driveway culverts, and landscaping to drain wet spots on the lawn.

4.1.2 Dual-wall Corrugated HDPE Pipe

Dual-wall corrugated HDPE pipe has a smooth liner that improves hydraulics and longitudinal strength of the pipe. Dual-wall corrugated HDPE pipe is preferred for stormwater drainage due to its light weight, high strength and premium hydraulics characteristics. A typical cross-section of a dual-wall HDPE pipe profile is shown in
Figure 4.2.

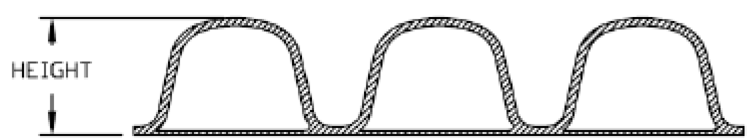

Figure 4.2: Dual-wall pipe profile cross-section

Dual-wall corrugated HDPE manufacturers provide various pipe joining methods depending on the pipe style and project requirements. Pipe joints are available with an integral bell and gasketed spigot joints, which are most commonly used for dual-wall corrugated HDPE. Another type of jointing system for dual-wall pipe is a coupling band, which wraps around the pipe and is secured with plastic ties.

The available diameters for dual-wall corrugated HDPE range from 4 in. to 60 in. (10 cm to 150 cm) and it is most commonly available in approximately 20-ft (6.1-m) lengths. Shorter lengths (e.g., 10 and 13 ft (3 and 4 m)) may be available to facilitate the use of trench box safety equipment for the deeper installations. Longer length and custom lengths may also be available. Figure 4.3 shows a typical dual-wall pipe installation.

Figure 4.3: Dual-wall HDPE pipe installation

Dual-wall corrugated HDPE is predominately used in storm sewer and culvert applications. Widespread acceptance and installation of the product has led to its rapid growth in municipal, highway, subdivision, and commercial development. Specific applications include, but are not limited to the following:

- Culverts and cross drains;
- Storm sewers;
- Underground retention/detention;
- Ditch enclosures;
- Mining;
- Sub-surface drainage; and,
- Industrial.

4.1.3 Dual-wall Corrugated Polypropylene Pipe

Dual-wall corrugated polypropylene (PP) pipe is commercially-available in 12 to 60-in. (300 to 1500 mm) diameters and typically 20 ft (6 m) lengths. Shorter corrugated PP pipe lengths may be available if used with trench box safety equipment for the deeper installations. It often has a cross-section that is almost identical to the dual-wall corrugated HDPE shown in Figure 4.2. The PP material has a higher flexural modulus than HDPE; therefore, the resulting pipe is stiffer than corrugated HDPE pipe. In addition to being used for culvert and storm sewer applications, dual-wall corrugated PP pipe has gained market acceptance as a viable sanitary sewer product. Dual-wall corrugated PP pipe is produced with an integral bell and spigot pipe jointing system that can meet or exceed most watertight requirements.

4.1.4 Triple Wall Corrugated Polypropylene Pipe

Triple wall corrugated polypropylene (PP) pipe has both a smooth interior and exterior. Figure 4.4 presents a typical cross-section for a triple wall corrugated PP pipe profile. This product is currently available in 30 to 60 in. (750 to 1500 mm) diameters. Triple wall corrugated PP pipe has a watertight integral bell and spigot with single- or double-gasketed spigot configurations and a standard length of 20 ft (6 m), as seen in Figure 4.5.

Shorter lengths are available to facilitate the use of trench box safety equipment for the deeper installations.

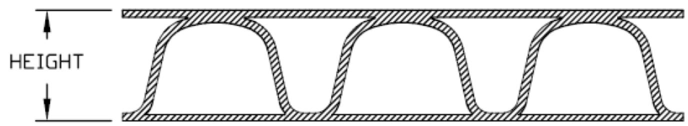

Figure 4.4: Triple wall corrugated pipe profile cross-section

Figure 4.5: Triple wall corrugated pipe installation

4.1.5 Perforated Corrugated Pipe

For subsurface water collection or leaching action, single-wall and dual-wall CPP can be perforated to accelerate the removal of subsurface water in soils or to allow stormwater to percolate into the soil. Perforations typically come in one of two styles: narrow slots or drilled holes. Perforated pipes come in a multitude of patterns and are typically dictated by AASHTO and ASTM standards.

4.1.6 Pipe Joints and Coupling Systems

CPP is available in a number of pipe joint configurations. Single-wall corrugated pipe joints are developed for their unique land drainage applications; whereas, the dual-wall corrugated pipe joints are developed for more demanding highway and municipal applications. Regardless of the application and pipe type, the pipe jointing systems can be divided into three categories: soil-tight, silt-tight, and watertight. The specific performance levels and material requirements of these pipe joints can be found in a number of ASTM and AASHTO standards.

Table 4.1 provides a summary of joint systems available for CPP, along with a brief description of each and current testing standards.

Table 4.1: Summary of joint systems

Joint Type	**Joint Description**	**Laboratory Test Protocol**	**Field Test Protocol(s)**
Soil- tight	Soil-tight joints prohibit the migration of soil larger than No.200 sieve through the joint. If the size of the opening exceeds 0.75 in. (3 mm), the length of the channel should be at least four times the size of the opening. Soil-tight joints may utilize connecting bands, elastomeric rubber seals, geotextile wrap, or an applied bulk mastic sealant.	Assemble pipe joint and measure the opening.	Visual for proper assembly.
Silt-tight	Silt-tight joints prohibit the migration of soil smaller than No.200 sieve through the joint Silt-tight joints may utilize connecting bands, elastomeric rubber seals, geotextile wrap, or all.	Joints utilizing gasket only as silt-tight seal shall be designed to pass ASTM D3212 (1) laboratory test of 2 psi (13.7 kPa) pressure. Geotextile wrap shall meet AASHTO M288 (2), with an Apparent Opening Size (AOS) > 70.	Visual for excessive leakage or leakage carrying soil fines.
Watertight	Watertight joints are specified where limited joint leakage is acceptable. The allowable rate is 200 gallons/inch-diameter/mile/day.	Joints meeting leak resistant criteria shall be designed to pass the ASTM D3212 (1) laboratory test/proof of design test that demonstrates compliance with the leakage rate at the	ASTM F1417 Standard Test Method for Installation Acceptance of Plastic Gravity Sewer Lines Using Low Pressure Air (3), and ASTM F3058 Preliminary Field Testing of Thermoplastic Pipe Joints for Gravity Flow (Non-Pressure) Sewer Lines (4)

		specified head or pressure.	Visual for leakage and/or specified standard test methods for installation acceptance of gravity sewer lines using low pressure air or water, or vacuum.

Dual-wall corrugated pipe joints typically have a bell that is formed as an integral part of the pipe (i.e., integral bell) and a spigot that is formed in the pipe as shown in Figure 6. The bell and spigot for most pipe products is developed to maintain a constant outside diameter that avoids additional excavation for the bells and improves the consistency of the final grade during installation.

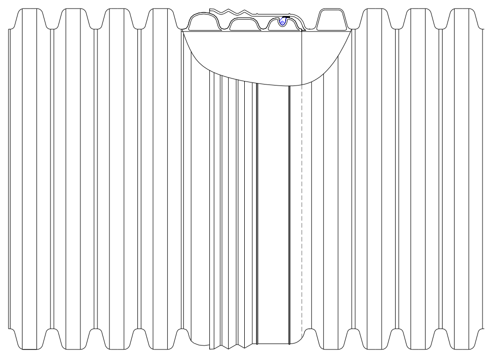

Figure 4.6: Typical integral bell and spigot CPP design

4.2 Applications

CPP is used in a wide variety of applications. Due to the versatility of the product and the continuous evolution of applications, there are too many applications to be completely covered in this Handbook. However, the broad categories for the application of CPP are culverts, storm sewers, sanitary sewer, agricultural, and industrial applications.

4.2.1 Culverts and Highway Drainage

Culverts are used to transition stormwater flow from open streams (e.g., ditches or natural waterways) and distribute it beneath a manmade structure (e.g., driveway, roadway, embankment, or levee). The culvert then discharges the water back into the open stream. Culverts are generally less than 300 ft. (91 m) long, and the hydraulic flow within the culvert is largely governed by inlet and outlet conditions. CPP are used in a wide variety of culvert applications from driveway culverts to more demanding railroad applications. Minimum and maximum cover heights are important design considerations and ensure that the pipe is structurally capable of handling the loads. Culvert hydraulics should be evaluated to ensure flow does not overtop the road.

Highway and municipal culverts are typically 12 to 60 in. (30 to 150 cm) in diameter. The ability to handle traffic loads with minimal cover makes CPP an excellent choice for culverts. A variety of pipe joints can be used in the highway and municipal culvert applications. The specific pipe joint depends on site conditions but is typically soil-tight. Pipes are available in 20 ft (6 m) lengths to minimize the installation time and number of joints, allowing for shorter road closure times.

The use of CPP for culvert applications has been thoroughly tested and researched. One of the earliest investigations of corrugated HDPE pipe acceptance for a highway culvert application under a state highway was installed by the Ohio DOT in September 1981. The project was to replace a failing culvert that had collapsed due to corrosion from an effluent with a low pH (pH < 4). The corrugated HDPE pipe culvert is still in service, and its condition appears to be unchanged, as shown in Figure 4.7. Based on the success of this project and others, roadway maintenance departments use corrugated HDPE pipe extensively to replace pipe of other materials in areas where corrosion has been a challenge.

Figure 4.7: Installation of 24-inch diameter culvert since 1981 in acid mine run-off

The AASHTO specifications have also had significant impact on the industry's growth in culvert and highway drainage applications. AASHTO specifications for CPP are referenced by the DOTs, Federal Highway Administration, Federal Aviation Administration, U.S. Army Corps of Engineers, and other governmental agencies.

The AASHTO M 252 specification for Corrugated Polyethylene Drainage Pipe was first published by AASHTO in 1976 and was intended primarily for underdrain or subsurface drain applications (5). AASHTO M 252 covers diameters from 4 to 10 in. (100 to 250 mm), both corrugated and smooth interior.

In 1986, AASHTO M 294, Corrugated Polyethylene Pipe for 300 to 1500-mm Diameter, was published. Initially, the AASHTO M 294 specification included 12 to 24 in. (300 to 600 mm) diameter pipes. As the number of available pipe diameters has increased, and the appropriate testing on those diameters was done, larger sizes were added to the standard including up to 60 in. (1500 mm). Based on recently completed research, M 294 allows both virgin and recycled resins (6).

Corrugated PP pipe was added as the AASHTO M 330 standard specification (7) and includes pipe diameters from 12 to 60 in. (300 to 1500 mm).

In addition to material standards, AASHTO has published design standards, construction standards, and a quality assurance program as shown in Table 4.2. All of these standards have served to broaden acceptance and increase confidence in these products. They also serve to establish minimum performance and manufacturing standards for these products.

Table 4.2: AASHTO standards

AASHTO Standards Committees	Standard Developed
Subcommittee on Materials	AASHTO M 252 (5) AASHTO M 294 (6) AASHTO M 330 (7)
Subcommittee on Bridges and Structures – Design	AASHTO LRFD Bridge Design Specifications – Section 12 (8)
Subcommittee on Bridges and Structures – Construction	AASHTO LRFD Bridge Construction Specifications Section 30 (9)
National Transportation Product Evaluation Program	NTPEP for Thermoplastic Pipe (10)

4.2.2 Railroad

Some of the most rigorous culvert applications are for railroad and intermodal facilities. These culverts are subjected to extremely high loads, shallow cover, and numerous loading cycles. Corrugated HDPE pipe has been used for many years as culverts in railroad applications and intermodal facilities. The American Railway Engineering and Maintenance-of-Way Association (AREMA) has approved the use of CPP for culverts (11).

PPI funded a study at the American Association of Railroad's (AAR's) Transportation Technology Center, Inc. (TTCI) in Pueblo, Colorado, in which two 48-in. (1200-mm) diameter HDPE pipes were installed under the test track and subjected to one million load cycles (12).

Figure 4.8 and 4.9 include images of the installed pipe at the test TTCI test track facility. The pipe performed successfully and based on this test, corrugated HDPE pipe was included in the AREMA standards for culvert applications under track.

Figure 4.8: AAR TTCI test installation

Figure 4.9: AAR TTCI test installation in progress

For many of the newer rail lines, CPP is particularly well-suited because it is a dielectric and is not affected by stray current corrosion. Transit systems and high-speed rail systems are all electrified rail. Design engineers are often concerned about the corrosive effects on metal pipe and reinforced concrete pipe due to stray currents. Therefore, as a result of the AREMA approval and its dielectric properties, CPP is experiencing widespread use in rail applications.

4.2.3 Storm Sewer

Storm sewer systems require a wide range of pipe sizes and meet the requirements in landscaped, public ROW, parking, and traffic areas. Corrugated HDPE is proven to be a durable and cost-effective pipe material for storm sewer applications. Most state DOTs, cities, and counties have included CPP in their standard construction specifications.

Storm sewer pipes are generally found in urban areas where stormwater is collected from a combination of stream flow, surface runoff, and street runoff. The hydraulic evaluation for these systems is based on gravity flow but may include intermittent times when the system is surcharged (i.e. pressurized). As with any pipe material, proper selection of the pipe joint is an important design consideration. In cases where the system is subjected to surcharge conditions and fine grain backfill is present, a silt-tight or watertight pipe joint is recommended. The smooth interior of double wall or triple wall CPP provides a hydraulic advantage and reduces clogging, especially for areas in which it is challenging to achieve a minimum slope or flow velocity.

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CPP is the predominant material used in many areas for commercial and municipal storm sewer applications. Municipal applications are generally considered to be utilities for cities and counties. These include systems installed as a capital improvement project or by a developer, who later turns the storm sewer system over to the public agency for maintenance. Commercial storm sewer applications are considered to be private development, which may include parking lots, shopping centers, and other related developmental projects that are funded and maintained by private sources.

CPP has been approved and used for a wide range of highway transportation system applications including storm sewer systems, running parallel and/or beneath roadways. Storm sewers for the highway transportation system are similar to those used in the municipal storm sewers and surcharge conditions may be experienced; therefore, pipe joints are typically rubber-gasketed bell and spigot joints.

When storm drainage systems are used by the federal government, CPP can be specified by referencing UFGS Section 33 40 00 (13).

4.2.4 Subsurface Drainage

Subsurface drainage is generally described as drainage systems that remove groundwater. However, subsurface drain systems can be installed to remove surface water and to improve the movement of traffic on the surface. Typical applications of subsurface drainage include highway edge drains or under drains, agricultural drainage, recreational field drains (i.e., golf courses, football fields, etc.), toe drains, and French drains.

Highway Underdrains

CPP was first used on a highway project as an underdrain in the early 1970s by the Iowa DOT on Interstate I-80 and by the Georgia DOT on Interstate I-16. The Georgia DOT was the first agency to include corrugated HDPE in their standard specifications by referencing an ASTM specification developed for agricultural drains. The I-16 project in Georgia had 192,000 linear ft. (58,560 m) of 4-in. (100-mm) underdrain pipe installed at an average rate of 2,000 ft (610 m) per day per by a crew in 1974. Soon after, the FHWA issued "*Implementation Package 76-9, Slotted Underdrain Systems*" in June 1976 (14) which detailed the use, installation requirements, limitations, and performance of underdrain materials including corrugated steel pipe, corrugated HDPE pipe, and slotted PVC pipe. Advancements in trenching and installation of highway underdrain has continued to evolve since those early installations, and corrugated HDPE pipe is the predominant product used for highway underdrains.

Recreational Field Subsurface Drains

Recreational field subsurface drains include use for turf drainage, golf courses, and athletic fields. Perforated drainage pipe is widely used to provide underdrain on golf course fairways, rough, and greens.

In addition, professional football, baseball, and soccer field, as well as at colleges and universities, in North America are drained with CPP systems. Subsurface drainage is designed to remove a given rainfall quantity at a prescribed rate to remove rainwater and maximize the playing time on the field. The turf drainage lines are typically 4 to 6-in. (100 to 150 mm) in diameter, placed at a depth of 12 to 18 in. (300 to 450 mm), and placed relatively close together at 10 to 20 ft (3 to 6 m) increments. Collector mains are used to gather the water from the subsurface drainage lines and then transport it away from the playing surface. This runoff is often stored for re-use as irrigation water.

4.2.5 Airports

The first major airport drainage project using CPP was for the Jacksonville, Florida airport in 1976. This project utilized corrugated HDPE pipe for underdrain along and across the runway. Since then, CPP has been used for underdrain, stormwater collection, and water treatment applications at many airports throughout the United States including in Atlanta Hartsfield, Dallas Fort Worth, Denver International, Pittsburgh, and Chicago O'Hare and is approved for use by the Federal Aviation Administration Standards for Specifying Construction of Airports Advisory Circular No. 150/5370-10C (15). For instance, Denver International Airport has used over 50 miles (80 km) of 6-in. (150-mm) diameter underdrain pipe in the construction of their runways, taxiways, and roads.

Figure 4.10: Typical airport project

Airport applications for CPP present their own unique set of considerations. Most standard designs for CPP involve standard truck and tandem wheel configurations. However, aircraft loading requires pipe design for both aircraft and vehicle loading. De-icing stations may require both collection and holding of de-icing runoff for special handling. Therefore, watertight joints are often specified for airport applications that involve stormwater runoff or deicing stations.

4.2.6 Low Head Irrigation

The movement of water for irrigation in open ditches has been done for thousands of years. However, ditches lose a significant percentage of water by leaking into the ground and from evaporation from the open surface. Enclosing trenches or ditches with larger diameter, smooth interior corrugated pipe can eliminate these losses and maintain water quality from the source to where it is ultimately needed. The development of larger diameter pipe and higher performing pipe joints, combined with the scarcity of water, has all lead to the use of CPP for ditch enclosures.

The use of CPP in these applications has enabled large quantities of water to be kept from evaporating and infiltrating in the western part of the United States. This is particularly important as water becomes more scarce in these areas. Coordination with the design engineer and/or the owner is critical to comply with the pipe joint requirements, operating pressures, and surge pressures that are necessary for a successful project. When properly designed, CPP can provide an economical solution and can facilitate long service lives.

4.2.7 Gravity Flow Sanitary Sewer

CPP has been used with on-site septic systems for many years. In these applications, CPP is installed downstream from a septic tank and conveys the water to a leach field, and then perforated CPP delivers the water across the leach field. These systems must meet state and local standards for private on-site septic systems, and the systems are maintained by private land owners.

Sanitary sewers generally fall under the control of cities, counties, and sanitary sewer districts. With the development of smooth interior pipe manufactured from high-quality resins and with testable watertight pipe joints, CPP has been accepted for sanitary sewer applications, especially as larger diameter transmission mains. Common pipe standards used for these applications include, ASTM F2763 (16), ASTM F2764 (17), and ASTM F2947 (18). For these applications, CPP is available in 13- and 20-ft (4- and 6-m) lengths and provides a cost-efficient alternative that can be quickly and efficiently installed. Site conditions associated with sanitary sewer are often different than standard drainage projects. As with any sanitary sewer project, the influence of deep burial depths and groundwater should be evaluated.

4.2.8 Stormwater Management

Urbanization of land can dramatically alter the natural movement of water by increasing impervious cover which can increase runoff from the developed land. This increased runoff may result in an increase of downstream flow, especially during periods of peak flow. As a result of this increased flow, cities and states have implemented regulations to limit the rate of stormwater runoff as well as the level of pollutants that are permitted in discharged stormwater. To counter these problems, stormwater detention systems hold peak flows until the existing storm drainage trunk systems and ditches are capable of accepting the additional flow, and until the peak flow has subsided.

Additionally, when runoff is transported away from critical areas, it can cause problems with the recharging of aquifers. To counter these problems, stormwater retention systems can hold runoff until the surrounding soil can accept it via percolation, which can then allow for the aquifers to be recharged.

Stormwater retention and detention systems can be either above-ground ponds or subsurface piping. Above-ground ponds may present child safety hazards and long-term aesthetic problems, such as insect breeding, weed growth, odor, and the need for refuse control. Subsurface retention/detention systems use available land more efficiently at a lower maintenance cost, while posing little to no public safety or aesthetic problems. Underground storage facilities developed by placing several pipes in series is also a common use of CPP.

Retention Systems

Retention systems are used when stormwater runoff has no outlet for disposal or when aquifers are in need of recharging. CPP used in these systems is perforated to allow the water to infiltrate into the ground and ultimately to aquifers. Important design criteria include the percolation rate of the native soils and the expected flow from storm events. These design criteria factor into a properly-sized footprint of the retention system, which will ensure that the system is capable of infiltrating sufficient quantities of water before the next rain event.

Detention Systems

Detention systems store stormwater from a peak flow and slowly discharge the water into an existing storm sewer system, stream, or ditch to attenuate the peak flow with the specific site. Detention systems are typically designed as a matrix of parallel runs of pipe with a manifold at one or both ends of the pipe as shown in Figure 4.11. Many of the pipe manufacturers have software programs to assist in the layout and design of the system. Often the manufacturers can provide a layout to assist with minimizing the amount of pipe and associated costs while meeting the stormwater storage requirement for the site. Another important consideration in the proper design of a detention system is the inclusion of flow from roof leaders.

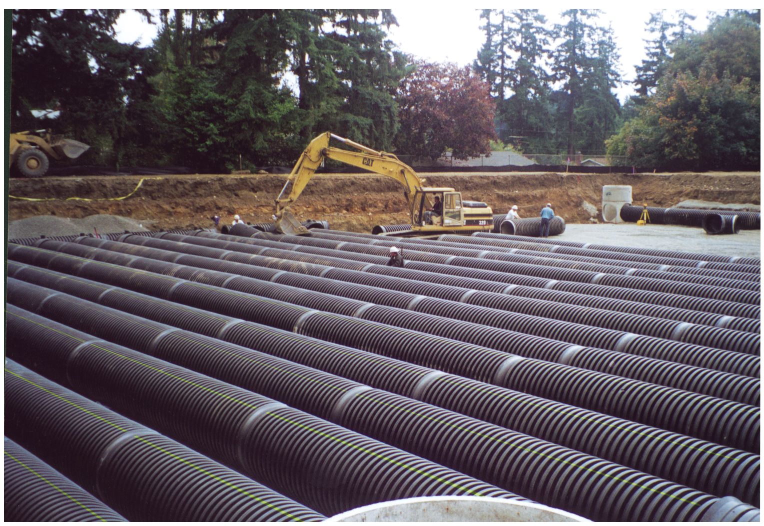

Figure 4.11: Typical detention system

CPP is ideally suited for use in underground stormwater management systems for a variety of reasons. Due to the storage needs and any individual site geometry constraints, retention/detention systems often require unique designs and pipe configurations. CPP can be adjusted to any length necessary, and the standard fittings allow underground storage systems to be laid out and assembled in the most efficient manner. Lightweight CPP with complementary fittings improve safety and the speed of installing underground stormwater systems. Many retention/detention systems are located beneath parking areas and since CPP is designed for use beneath highway traffic loads, it is ideal for these applications. In cold weather climates, road salts and deicing chemicals may be held for extended periods within underground storage systems because CPP is not susceptible to corrosive conditions due to its inert nature. CPP systems can be designed with leak-resistant pipe joints if warranted by the project. On the other extreme, CPP can be supplied with perforations to encourage infiltration or for use in full retention systems.

4.2.9 Agricultural Drainage

Agriculture applications for corrugated HDPE are primarily associated with land drainage. The installation of perforated corrugated HDPE single-wall pipe is critical in northern climates where the growing seasons are short and the fields remain wet due to poor natural drainage. The ability to drain the fields quickly and plant crops in a timely manner is critical for obtaining maximized crop yields.

The predominant pipe used for the agricultural industry is 4-in. (100-mm) diameter perforated corrugated HDPE single-wall pipe, but other diameters are also used. Soil-tight pipe joints are used in most cases, and a typical installation involves plowing the pipe into the ground, rather than the traditional method of excavating a trench and installing backfill. These agricultural drainage systems are typically designed to follow the contour of the topography and are spaced to keep the soil dry for field access and to optimize crop yields.

Corrugated polyethylene pipe was initially offered in 10- and 20-ft (3- and 6-m) lengths, which substantially reduce the labor costs in installation. The development of large coils (e.g., some 4-in. (100-mm) diameter coils out over 3,000 ft (915 m) long), coupled with high speed trenchers have led to installation rates exceeding 10,000 ft (3,050 m) per working day. These long lengths of pipe make it economical for large-scale agricultural drainage applications, where plowing the product into the ground has changed the agricultural industry as shown in

Figure 4.12. The cost reduction resulting from the increased installation rates has resulted in the extensive use of CPP for agricultural drainage applications. An additional benefit is that the reduction in time needed to install drainage pipe in the field enables the field to become available for planting and harvesting much sooner.

Figure 4.12: Agricultural plowing installation operation

Larger diameter pipes are also used as part of land drainage systems. For example, long runs of pipe might require increased diameters to carry the accumulating inflow. Collector mains, in which smaller lines are connected to larger diameter lines, require larger sizes to carry the collected water to available discharge points. Larger diameters are also needed to enclose open ditches, which makes additional land available for production of crops and facilitates movement around the land.

Grain Aeration

Perforated corrugated HDPE pipe is used very effectively to aerate stored grains to prevent grain spoilage. These are generally larger diameter pipe systems with special perforation patterns that are installed under grain storage piles, either inside buildings or in covered outdoor storage systems. The perforation pattern and the size of the perforations is determined for each type of grain and for the size of the storage facility.

Pipe placed in the bottom of grain storage bins can introduce air via blowers to evaporate moisture from the grain piles.

4.2.10 Relining and Sliplining

CPP can be used as a structural insert inside failing culverts, storm drains, or sewers made of corrugated metal or concrete, as shown in Figure 4.13. The CPP becomes the load-bearing structure after the annulus is filled with grout. CPP with a smooth interior must be inserted from a pit or inserted at the end of the existing culvert. The inserted CPP will reduce the original inlet area. If the reduction is too drastic, a short specially-designed taper may be attached to the inlet end to increase the hydraulic capacity of the lined pipe.

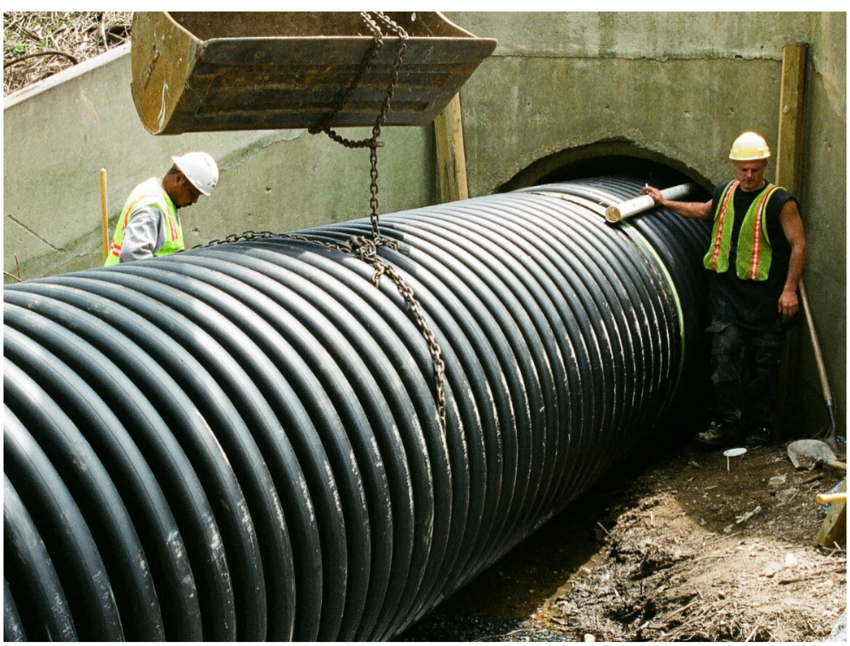

Figure 4.13: Delaware DOT reline project

4.2.12 Mining Applications

The mining industry has a special application of subsurface drainage that is ideal for perforated corrugated HDPE pipe. A process called heap leaching is used to recover low-grade deposits of copper, gold, nickel, silver, uranium, and zinc (as in Figure 4.14). This process involves placing crushed ore in piles over a geomembrane liner and perforated corrugated HDPE pipe. Chemicals are subsequently sprayed over the ore containing the minerals. The chemicals are then collected via the perforated HDPE and processed to remove the minerals in the solution. HDPE is well-suited to this process because it is highly resistant to chemical attack.

Figure 4.14: Typical heap leach pad construction

Mining sites include many of the same applications as other civil engineering construction sites, but with differences in scale. Trucks moving across the site can weigh as much as 4 million pounds (1,814 metric tons) and travel at 40 miles (64 km) per hour. ASTM F2986 (19) and F2987 (20) both provide information on material design properties used in these applications. An example of one of these large earth-moving vehicles is shown in

Figure 4.15.

Figure 4.15: Typical mining truck on a haul road crossing PE culverts

4.2.13 Industrial Applications

The chemical resistance of CPP pipes has led to their extensive use in other industrial applications. Both perforated pipe and solid pipe with watertight joints are used in applications where contaminants or process chemicals are present. CPP can be used as site drainage around chemical plants to remove pollutants from the site and transfer them to a treatment site. CPP is also used in conjunction with the cleanup of brownfield sites to make those sites useable for other purposes. CPP is used to drain the contaminants away or to remove volatile chemicals such as benzene by blowing air through perforated pipe installed in the contaminated soil. Because of its chemical resistance, CPP is not attacked or adversely affected by these chemicals.

References

1. **ASTM International.** ASTM D3212: Standard Specification for Joints for Drain and Sewer Plastic Pipes Using Flexible Elastomeric Seals. *ASTM International.* Conshohocken, PA : ASTM International, 2013.

2. **AASHTO.** AASHTO M 288: Standard Specification for Geosynthetic Specification for Highway Applications. *AASHTO State Materials Specifications.* Washington, DC, USA : AASHTO, 2018.

3. **ASTM International.** ASTM F1417: Standard Test Method for Installation Acceptance of Plastic Gravity Sewer Lines Using Low Pressure Air. *ASTM International.* Conshohocken, PA : ASTM International, 2018.

4. **ASTM International.** ASTM F3058: Preliminary Field Testing of Thermoplastic Pipe Joints for Gravity Flow (Non-Pressure) Sewer Lines. *ASTM International.* Conshohocken, PA : ASTM International, 2018.

5. **AASHTO.** AASHTO M 252-18: Standard Specification for Corrugated Polyethylene Pipe. *AASHTO State Materials Specifications.* Washington, DC, USA : AASHTO, 2018.

6. **AASHTO.** AASHTO M 294-18: Standard Specification for Corrugated Polyethylene Pipe, 300- to 1500-mm Diameter. *AASHTO State Materials Specifications.* Washington, DC, USA : AASHTO, 2018.

7. **AASHTO.** AASHTO M 330-18: Standard Specification for Corrugated Polypropylene Pipe. *AASHTO State Materials Specifications.* Washington, DC, USA : AASHTO, 2018.

8. **AASHTO.** AASHTO Bridge Design Specification, Section 12. *AASHTO State Bridge Specifications.* Washington, DC, USA : AASHTO, 2019.

9. **AASHTO.** AASHTO Bridge Construction Specification, Section 30. *AASHTO State Bridge Specifications.* Washington, DC, USA : AASHTO, 2019.

10. **AASHTO.** National Transportation Product Evalucation Program. *Workplan for Thermoplastic Pipe.* Washington, DC, USA : AASHTO, 2019.

11. **AREMA.** AREMA Manual. AREMA Manual, Part 4, Section 4.8. In A. R. Association, *AREMA MANUAL FOR RAILWAY ENGINEERING,* 2016.

12. **LoPresti, J. A.**. Corrugated Polyethylene Pipe Test Under 315,000-Pound Cars at FAST Report # P-09-052. Dallas: Plastic Pipe Institute. 2010.

13. **USACE**. Division 33 - Utilities Section 33 40 00. In U. S. Engineers, *Unified Facilities Guide Specification.* Washington: USACE. 2016.

14. **Federal Highway Administration**. *Implementation Package 76-9, Slotted Underdrain Systems.* 1976.

15. **FAA**. (2008). Advisory Circular 150/5370-10D. In U. D. Administration, *Advisory Circular.* Landover: US Department of Transportation, Sebsequent Business Office.

16. **ASTM International.** ASTM F2763: Standard Specification for 12 to 60 in. [300 to 1500 mm] Dual and Triple Profile-Wall Polyethylene (PE) Pipe and Fittings for Sanitary Sewer Applications. *ASTM International.* Conshohocken, PA : ASTM International, 2016.

17. **ASTM International.** ASTM F2764: Standard Specification for 6 to 60 in. [150 to 1500 mm] Polypropylene (PP) Corrugated Double and Triple Wall Pipe and Fittings for Non-Pressure Sanitary Sewer Applications. *ASTM International.* Conshohocken, PA : ASTM International, 2019.

18. **ASTM International.** ASTM F2947: Standard Specification for 150 to 1500 mm [6 to 60 in.] Annular Corrugated Profile-Wall Polyethylene (PE) Pipe and Fittings for Sanitary Sewer Applications. *ASTM International.* Conshohocken, PA : ASTM International, 2019.

19. **ASTM International.** ASTM 2986: Standard Specification for Corrugated Polyethylene Pipe and Fittings for Mine Leachate Applications. *ASTM International.* Conshohocken, PA : ASTM International, 2017.

20. **ASTM International.** ASTM 2987: Standard Specification for Corrugated Polyethylene Pipe and Fittings for Mine Heap Leach Aeration Applications. *ASTM International.* Conshohocken, PA : ASTM International, 2018.