



Virginia Center *for* Transportation
INNOVATION
& **RESEARCH**

Evaluation of Polypropylene Drainage Pipe

http://www.virginiadot.org/vtrc/main/online_reports/pdf/11-r14.pdf

EDWARD J. HOPPE, Ph.D., P.E.
Senior Research Scientist

Final Report VCTIR 11-R14

VIRGINIA CENTER FOR TRANSPORTATION INNOVATION AND RESEARCH

530 Edgemont Road, Charlottesville, VA 22903-2454

www.VTRC.net

Standard Title Page—Report on State Project

Report No.: VCTIR 11-R14	Report Date: March 2011	No. Pages: 25	Type Report: Final	Project No.: 93179
			Period Covered: May 2009–August 2010	Contract No.:
Title: Evaluation of Polypropylene Drainage Pipe				Key Words: Polypropylene pipe, plastic pipe, drainage, field evaluation, culvert, sewer, durability.
Author: Edward J. Hoppe, Ph.D., P.E.				
Performing Organization Name and Address: Virginia Center for Transportation Innovation and Research 530 Edgemont Road Charlottesville, VA 22903				
Sponsoring Agencies' Name and Address: Virginia Department of Transportation 1401 E. Broad Street Richmond, VA 23219				
Supplementary Notes:				
<p>Abstract:</p> <p>The purpose of this study was to conduct a field evaluation of polypropylene pipes in order to assess their potential suitability for drainage applications. The specific objectives were (1) to document the product handling during installation, and (2) to evaluate the in-situ performance under service conditions.</p> <p>The Virginia Department of Transportation (VDOT) selected five test locations on low-volume rural roads in Albemarle County where the field evaluation would occur. Installation of the pipes was carried out by a VDOT maintenance crew. In all cases, polypropylene drainage pipes replaced the existing corrugated metal and concrete pipes that had reached the end of their service life. No material testing of any kind was carried out on the pipes. It was understood that the limited scope of the study would not result in any conclusive assessment regarding the particular product's potential long-term performance.</p> <p>The dual- and triple-wall plastic pipes with nominal diameters of 30 and 48 in were supplied by ADS, Inc. The installation process was documented, and periodic field observations were conducted during the subsequent 1 year of service. As part of the evaluation, cross-sectional measurements were conducted at 2.5-ft intervals on all installed pipes.</p> <p>The results indicated that after 1 year of service, the maximum deformations of all pipes were less than 5 percent, satisfying current VDOT post-installation inspection requirements. No signs of crushing, buckling, or material degradation were detected.</p> <p>The results of the study indicate that polypropylene pipe offers a number of potential benefits when used in drainage applications. The durability of a plastic pipe must be resolved adequately in order to facilitate widespread product usage. In the case of polypropylene pipe, the issue of degradation attributable to material oxidation is extremely important. For many transportation projects, the owner must have a reasonable degree of assurance that the material will perform satisfactorily for at least 50 years. Fortunately, test methods for the durability assessment are currently available. It is possible that as users become more familiar with polypropylene pipe, they will increasingly regard it as a viable alternative in terms of life cycle costs. The product appears to lend itself to further evaluation as a promising innovative design.</p> <p>The report provides recommendations regarding the potential future acceptance protocol for polypropylene pipes on culvert and storm sewer projects. The recommendations include a durability assessment by an independent laboratory and a field verification of performance on the VDOT network.</p>				

FINAL REPORT
EVALUATION OF POLYPROPYLENE DRAINAGE PIPE

Edward J. Hoppe, Ph.D., P.E.
Senior Research Scientist

Virginia Center for Transportation Innovation and Research
(A partnership of the Virginia Department of Transportation
and the University of Virginia since 1948)

Charlottesville, Virginia

March 2011
VCTIR 11-R14

DISCLAIMER

The contents of this report reflect the views of the author, who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Virginia Department of Transportation, the Commonwealth Transportation Board, or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation. Any inclusion of manufacturer names, trade names, or trademarks is for identification purposes only and is not to be considered an endorsement.

Copyright 2011 by the Commonwealth of Virginia.
All rights reserved.

ABSTRACT

The purpose of this study was to conduct a field evaluation of polypropylene pipes in order to assess their potential suitability for drainage applications. The specific objectives were (1) to document the product handling during installation, and (2) to evaluate the in-situ performance under service conditions.

The Virginia Department of Transportation (VDOT) selected five test locations on low-volume rural roads in Albemarle County where the field evaluation would occur. Installation of the pipes was carried out by a VDOT maintenance crew. In all cases, polypropylene drainage pipes replaced the existing corrugated metal and concrete pipes that had reached the end of their service life. No material testing of any kind was carried out on the pipes. It was understood that the limited scope of the study would not result in any conclusive assessment regarding the particular product's potential long-term performance.

The dual- and triple-wall plastic pipes with nominal diameters of 30 and 48 in were supplied by ADS, Inc. The installation process was documented, and periodic field observations were conducted during the subsequent 1 year of service. As part of the evaluation, cross-sectional measurements were conducted at 2.5-ft intervals on all installed pipes.

The results indicated that after 1 year of service, the maximum deformations of all pipes were less than 5 percent, satisfying current VDOT post-installation inspection requirements. No signs of crushing, buckling, or material degradation were detected.

The results of the study indicate that polypropylene pipe offers a number of potential benefits when used in drainage applications. The durability of a plastic pipe must be resolved adequately in order to facilitate widespread product usage. In the case of polypropylene pipe, the issue of degradation attributable to material oxidation is extremely important. For many transportation projects, the owner must have a reasonable degree of assurance that the material will perform satisfactorily for at least 50 years. Fortunately, test methods for the durability assessment are currently available. It is possible that as users become more familiar with polypropylene pipe, they will increasingly regard it as a viable alternative in terms of life cycle costs. The product appears to lend itself to further evaluation as a promising innovative design.

The report provides recommendations regarding the potential future acceptance protocol for polypropylene pipes on culvert and storm sewer projects. The recommendations include a durability assessment by an independent laboratory and a field verification of performance on the VDOT network.

FINAL REPORT

EVALUATION OF POLYPROPYLENE DRAINAGE PIPE

Edward J. Hoppe, Ph.D., P.E.
Senior Research Scientist

INTRODUCTION

Currently, polypropylene plastic pipes are not allowed for drainage applications on the Virginia Department of Transportation (VDOT) road network. These products are relatively new to North America, and their applications in transportation projects at U.S. state departments of transportation (DOTs) are not extensively documented. They have been used for underground drainage and sewerage applications in Europe for approximately 30 years.¹

VDOT's Materials Division requested that the Virginia Transportation Research Council (now the Virginia Center for Transportation Innovation and Research) (VCTIR) conduct a 1-year field evaluation of several polypropylene pipes manufactured by ADS, Inc. (ADS). The pipes were part of ADS' N-12 High Performance (HP) product line, which is made of impact-modified copolymer polypropylene. The product submittal by ADS indicated that N-12 HP pipes were designed for gravity flow storm and sanitary sewer applications.^{2,3}

PURPOSE AND SCOPE

The purpose of this study was to conduct a field evaluation of the ADS polypropylene pipes in order to assess their potential suitability for drainage applications. The specific objectives were (1) to document product handling during installation, and (2) to evaluate the in-situ performance under service conditions.

VDOT selected five test locations on low-volume rural roads in Albemarle County where the field evaluation would occur. In all cases, the ADS polypropylene pipes replaced the existing corrugated metal and concrete pipes that had reached the end of their service life. The installation process was documented and periodic field observations were carried out by representatives of VCTIR and ADS during the subsequent 1 year of service.

No material testing of any kind was carried out on the pipes. It was understood that the limited scope of the study would not result in any conclusive assessment regarding the particular product's potential long-term performance.

METHODS

Three tasks were performed to achieve the study objectives:

1. A literature review pertaining to the material properties of polypropylene was conducted.
2. The ADS polypropylene test pipes were installed at five test sites on low-volume rural roads in Albemarle County, Virginia.
3. A 1-year field evaluation of the installed pipes was conducted.

Literature Review

Literature on the current state of the practice with respect to testing and use of polypropylene drainage pipes in transportation infrastructure was identified. The search initially focused on peer-reviewed research and literature sources but quickly expanded to include trade publications and descriptions of ongoing use by state DOTs and other organizations, such as utility companies. Search tools included Engineering Index, TRISWorld, Mechanical and Transportation Engineering Abstracts, and VDOT OneSearch databases. The Google State DOT Search Engine was used in an effort to find documentation produced by state DOTs.

Pipe Installation at Test Sites

Polypropylene pipes supplied by ADS were installed at five test sites selected on low-volume rural roads in Albemarle County in close proximity to Charlottesville.

The test sites and the pipes installed at each site were as follows:

1. Route 684: 48-in-diameter, triple-wall pipe, 55 ft long
2. Route 736: 30-in-diameter, dual-wall pipe, 50 ft long
3. Route 635: 30-in-diameter, dual-wall pipe, 30 ft long
4. Route 635: 48-in-diameter, triple-wall pipe, 33 ft 6 in long
5. Route 698: 48-in-diameter, triple-wall pipe, 31 ft 2 in long.

Two pipe runs were of 30 in nominal internal diameter, and three runs were of 48 in internal diameter. The corresponding outside diameters were 35.4 and 53.8 in, respectively. Pipes were delivered in standard 20-ft sections; 30-in pipes had a dual-wall profile, and 48-in pipes had a triple-wall profile design. Figure 1 shows sections of the ADS dual- and triple-wall pipe profiles.



Figure 1. Dual-Wall and Triple-Wall Profiles of ADS Polypropylene Pipes

The stiffness of the pipe, was 46 psi at 5 percent deflection. Manning's n value was 0.012. Pipe joints were rated at 15 psi internal pressure. Extensive product data and design guidelines are available from ADS.²⁻⁸

Figure 2 is a map showing the test sites. Average daily traffic counts, obtained from the 2007 VDOT traffic survey indicated 910 vehicles per day (vpd) on Route 684, 60 on Route 736, 570 on Route 635, and 90 on Route 698.

Prior to installation, pipes were spot marked inside with paint at 2.5-ft intervals. Actual pipe diameters were manually measured using a steel tape at marked locations in the horizontal and vertical directions to establish baseline readings under no-load conditions. All subsequent field measurements and calculations were referenced to these initial readings.



Figure 2. Test Locations

Field Evaluation of Installed Pipes

Internal inspections and cross-sectional measurements were conducted after approximately 30, 120, 240, and 360 days following installation. Specifically, the following were documented during the installation and for a subsequent period of 1 year:

1. trench dimensions
2. type of backfill material used
3. placement and compaction process
4. height of cover
5. joint condition
6. pipe alignment
7. any evidence of material cracking, splitting, or delamination
8. internal vertical and horizontal pipe deformations at 2.5-ft intervals.

RESULTS

Literature Review

Most commonly used structural materials, such as steel or concrete, are elastic. Therefore, independently of the loading time, the stress-strain relationship is linear up to certain stress level as per Hooke's law and the material can recover its original shape after unloading. In the case of plastics, the strain is not proportional to stress or independent of the loading time,

exhibiting both elastic and viscous response.⁹ Such response can be compared to that of steel at high temperatures. Similar to steel, the tendency of plastics to creep is temperature and load dependent. Creep increases with increasing temperature. The consequence of creep is that the material failure will occur after a certain mechanical loading time, which is inversely proportional to the magnitude of stress. If the stress is held constant, the strain increases over time, resulting in creep. If the strain is held constant, the stress decreases with time, resulting in relaxation. The allowable design stress for a viscoelastic material is therefore dependent on the required service life of the application. Estimates of the material service life are usually based on the Arrhenius' logarithmic correlation that takes into account operating temperature and stress level.

Polypropylene is part of the polyolefins family. It is a versatile thermoplastic material used in many commercial applications.¹⁰ It is produced by polymerizing propylene in the presence of a catalyst. The starting material, propylene, is called the monomer, and the final compound is called the polymer. A long, linear polymer chain of carbon atoms is formed, with methyl groups attached to every other carbon atom of the chain. Thousands of propylene molecules can be added sequentially until the chain reaction is terminated. Depending on the catalyst used in production, polypropylene can be isotactic, syndiotactic, or atactic, based on the resulting orientation of the pendant methyl groups attached to alternate carbon atoms. In isotactic polypropylene, the most common commercial form, methyl groups are in the same configuration and are on the same side of the polymer chain. In syndiotactic polypropylene, alternate methyl groups are on opposite sides of the polymer backbone. In atactic polypropylene, methyl groups have a random orientation.

Because of its molecular structure, isotactic polypropylene has the highest crystallinity, resulting in a relatively high stiffness and tensile strength. This is the type of material selected by ADS for manufacturing of polypropylene pipes. Syndiotactic polypropylene is less stiff but has a better impact strength. The atactic version is least crystalline, resulting in a sticky, amorphous material. It is possible to combine various molecular structures to achieve desired properties. Generally, polypropylenes exhibit higher tensile, flexural, and compressive strength and higher moduli than polyethylenes. As with other thermoplastics, polypropylene is a viscoelastic material, with mechanical properties strongly dependent on time, temperature, and stress level.

In general, polypropylene exhibits excellent mechanical and chemical characteristics, including high strength, high stiffness, high resistance to stress crack propagation, and high chemical resistance. Because of its relatively high strength to weight ratio, it is more rigid than other polyolefins. Commercial grades of polypropylene are available in three distinct forms: homopolymer, random copolymer, and block copolymer. Homopolymer is produced by polymerizing only the polypropylene monomer. Copolymer is produced by polymerizing propylene with secondary monomers, typically ethylene and butene. The chemical process can be controlled so that the secondary units are present either as relatively long sequences (block copolymer) or as individual units (random copolymer). Typically, homopolymer is the most suitable choice for stiffness, chemical resistance, surface hardness, and chemical resistance. Block copolymer is suitable for impact strength, low-temperature strength, and toughness.

Random copolymer is most suited where flexibility is required. The optimum material selection is dictated by the particular application.

The behavior of polypropylene can be extensively shaped and modified by the use of additives. Unmodified polypropylene becomes brittle at sub-ambient temperatures. The manufacturing process used by ADS uses an impact copolymer grade of polypropylene with uncured ethylene propylene rubber as a modifier in order to balance stiffness and impact resistance. The raw material is provided by the resin supplier.

The melt flow rate is an indirect measure of the molecular weight of polymer. It is indicative of how easily the molten raw material will flow during processing. As the melt flow increases, some physical properties, such as impact strength, will decrease. ADS selected a melt flow rate below 0.5 g/10 min to optimize short- and long-term physical properties.

Polypropylene is highly susceptible to oxidation because of the presence of the tertiary hydrogen on the carbon atom bonded to the pendant methyl group. It undergoes oxidation more readily than polyethylene, resulting in a decreased molecular weight and a gradual loss of mechanical properties. Polypropylene can begin to disintegrate to an oxidized powder right after formation if no antioxidants are added during manufacturing.

Antioxidants inhibit the oxidation reaction by combining with free radicals or by reacting with hydroperoxides. Selection of the proper antioxidant combination is very important and depends on the product application requirements. Typically, antioxidant is added in the extrusion phase to form a stabilized resin. ADS pipes contain an antioxidant package provided by the resin supplier.

In outdoor exposure, polypropylene is susceptible to ultraviolet (UV) degradation. This effect is similar to that of oxidation and is evidenced by chalking and cracking of the surface and diminished mechanical properties. To counteract these effects, UV stabilizers are added during production. The ADS manufacturing process includes a customized UV package with additional antioxidants and pigments. It includes UV absorbing titanium dioxide and a hindered amine light stabilizer. This package is provided by a supplier. Polypropylene is usually stabilized right after polymerization.

Once relevant degradation mechanisms have been identified, tests designed to simulate particular field conditions are carried out to estimate durability. For polypropylene, the primary identified degradation mechanisms are oxidation and UV deterioration.¹¹ ASTM standards G166,¹² G169,¹³ and G172¹⁴ present some generally accepted statistical analysis methods that may be useful to establish correlations and estimate service life, but the durability of a material cannot be predicted based on statistical methods only. Some practices, such as ASTM G7,¹⁵ cover the procedures for direct environmental exposure. However, considering that the rate of degradation is usually very slow under service conditions, it becomes necessary to select test methods using a more aggressive environment in order to accelerate the degradation process and thus obtain the required results more expeditiously. It should be kept in mind that some degree of extrapolation is required with such an approach.

The laboratory test methods designed to assess the oxidation of polyolefins examine the effective lifetime of antioxidants in the polymer and the stability of the polymer itself.¹⁶ The oxidative induction time (OIT) test was developed to indicate the amount of antioxidants in the material. There are two types of OIT tests: the standard test performed in accordance with ASTM D 3895¹⁷ and the high-pressure test performed in accordance with ASTM D5885.¹⁸ The main application of the latter test is for antioxidants, such as hindered amines, with a low-efficiency temperature range. The European test method for determining the resistance to oxidation is ISO 13438.¹⁹ It uses a specially designed stirred autoclave device for high-temperature and high-pressure incubation. This approach combines oxidative stress with extraction of stabilizers and antioxidants in aqueous or moist environments. Resistance to the UV degradation is typically tested using ASTM D4355²⁰ or DIN EN 12224²¹ standards.

Hsuan and Koerner²² compared the results of standard and high-pressure OIT data on sample geomembrane material and predicted a lifetime of at least 200 years for the particular antioxidant package. This is in a stark contrast to data indicating that the unstabilized polypropylene has a functional life of less than 50 years.²³ Therefore, the effective service life of a polypropylene product depends to a large extent on the type and the remaining level of antioxidant additives. ADS specifies its polypropylene material for a minimum oxidation induction test time of 25 min. This represents a more conservative requirement than the one stipulated in the European Standard EN 13476-3, which calls for a minimum of 8 min.²⁴

Methods for measurement of tensile creep of geosynthetics have evolved over the years. One of the most significant recent contributions to the measurement of creep strain is ASTM Standard D6992.²⁵ It uses the so-called stepped isothermal method (SIM) to predict the load strain and creep rupture behavior at extended time periods and elevated temperatures. General principles of this method have been in use for a number of years in the polymer industry, and recently the method has been adapted for the testing of geosynthetic materials. It is considered to be an alternative to ASTM's Standard Test Methods for Tensile, Compressive, and Flexural Creep and Creep-Rupture of Plastics (ASTM D2990).²⁶ The results obtained from this test method are typically used to supplement the results of ASTM's Standard Test Method for Evaluating the Unconfined Tension Creep and Creep Rupture Behavior of Geosynthetics (ASTM D5262)²⁷ in order to construct a composite creep rupture envelope. Lothspeich and Thornton²⁸ demonstrated that the SIM test can be used to estimate a 114-year design life in geosynthetic reinforcing materials, including polypropylene. ADS conducts resin qualification testing and determines the material modulus of elasticity based on the ASTM D6992 standard.

The Washington State DOT (WSDOT) developed a comprehensive protocol for the determination of the long-term strength of geosynthetic reinforcement: WSDOT Standard Practice T 925: Standard Practice for Determination of Long-Term Strength for Geosynthetic Reinforcement.²⁹ This methodology has been adopted in numerous parts of the world as the protocol of choice for evaluating polypropylene, polyethylene, and polyester geosynthetics. A similar approach is presented in the ISO/TR 20432 guidelines for the determination of the long-term strength of geosynthetics for soil reinforcement.³⁰ They provide guidance for the assessment of material degradation based on various recommended tests. Typically, long-term durability tests are applicable to service in a non-aggressive environment, as defined in WSDOT T 925.

The Federal Highway Administration report *Corrosion/Degradation of Soil Reinforcement for Mechanically Stabilized Earth Walls and Reinforced Soil Slopes* provides some criteria for determining aging losses when geosynthetic reinforcement is used.³¹ It describes the oxidation and UV degradation of polyolefins and offers estimates of durability reduction factors that are applied to the ultimate tensile strength.

Existing design guidelines include NCHRP Report 631: *Test and Design Methods for Thermoplastic Drainage Pipe*.³² The report contains recommended LRFD design specifications for plastic pipes. It deals specifically with HDPE and PVC materials and provides design guidance for a 50-, 75-, and 100-year service life. ADS adapted NCHRP Report 631 as a template to design polypropylene pipes to meet LRFD specifications.

In 2010, ASTM published two standards dealing specifically with polypropylene plastic pipes for use in non-pressure applications (sanitary sewers, storm sewers, and drainage pipes). These standards include comprehensive requirements and test methods. ASTM F2736 pertains to pipes with diameters from 6 to 30 in.³³ ASTM F2764 addresses pipes with diameters from 30 to 60 in.³⁴ Both standards refer to ASTM D6992 for evaluating long-term strength.

The installation of all pipe types requires attention to the backfill work to ensure pipe integrity and satisfactory performance. The magnitude of the cross-sectional deformation in flexible pipes depends on the quality of backfill. Janson⁹ stated that if the compaction work was done “properly,” the cross-sectional pipe deformation should not exceed 6 percent as an average value for various thermoplastic pipes. This estimate is obviously higher than for typical, correctly installed rigid pipes and should be considered significant in specific applications where the magnitude of the ground settlement above the pipe may be a particular importance. Typically, this is a critical issue for railway crossings.

Documentation of Pipe Installation at Test Sites

1. Route 684: 48-in-diameter, triple-wall pipe, 55 ft long (Figure 3)

Installation date: May 4, 2009

Existing pipe: 36-in-diameter corrugated metal pipe (CMP)

Average trench width: 9 ft

Average trench depth: 6 ft

Bedding material: No. 57 stone

Backfill material: No. 26 crusher run aggregate

Average final height of cover at the road centerline: 1.8 ft

Notes:

- There was no backfill compaction from the bedding to the spring line. The crew superintendent stated that it is the standard practice with CMP pipe to prevent pipe lift and misalignment.



Figure 3. Installation of 48-inch Pipe at Route 684

- Compaction was performed in 8- to 10-in-deep lifts above the spring line using hand-operated compactors.
- The entire 55-ft-long pipe run was assembled outside the trench and then lowered in position using multiple supporting chains attached to a Gradall bucket.
- Backfill stone was piled on top of pipe to hold it in place.
- Riprap stone was hand placed around the pipe at each end.
- Approximately 10 in of mud and stone accumulated at the bottom of the pipe, making vertical measurements impossible. There was partial flow through at all times.
- The following defects were observed: inner liner dent at 50 ft upstream caused by the forklift, stress whitening at 40 ft upstream at the second joint (noted prior to pipe placement).

2. Route 736: 30-in-diameter, dual-wall pipe, 50 ft long (Figure 4)

Installation date: July 8, 2009

Existing pipe: 18 in diameter CMP twin run (one of the pipes was completely blocked)

Average trench width: 7 ft

Average trench depth: 5 ft

Bedding material: No. 26 crusher run (approx. 6 in)

Backfill material: No. 26 crusher run

Average final height of cover at the road centerline: 1.6 ft

Notes:

- There was no backfill compaction. Hand-operated compactors were not used.
- Surface compaction was carried out using Gradall Series 4100 excavator with rubber tires.
- The entire 50-ft-long pipe run was assembled outside the trench and then lowered in position using multiple supporting chains attached to a Gradall bucket.
- Backfill stone was piled on top of the pipe to hold it in place.
- Riprap stone was hand placed around the pipe at each end.
- No defects were observed.



Figure 4. Installation of 30-inch Pipe at Route 736

3. Route 635: 30-in-diameter, dual-wall pipe, 30 ft long (Figure 5)

Installation date: July 15, 2009

Existing pipe: 24-in-diameter combined reinforced concrete pipe (RCP) and CMP

Average trench width: 10 ft

Average trench depth: 6 ft

Bedding material: No. 57 stone (approx. 4 in)

Backfill material: No. 26 crusher run

Average final height of cover at the road centerline: 2.5 ft

Notes:

- There was no backfill compaction. Hand-operated compactors were not used.
- Surface compaction was carried out using Gradall Series 4100 excavator with rubber tires.
- The entire 30-ft-long pipe run was assembled outside the trench and then lowered in position using multiple supporting chains attached to a Gradall bucket.
- Backfill stone was piled on top of the pipe to hold it in place.



Figure 5. Installation of 30-inch Pipe at Route 635

- Riprap stone was hand placed around the pipe at each end.
- Observed defects were minor forklift indentations inside the pipe.

4. Route 635: 48-in-diameter, triple-wall pipe, 33 ft 6 in long (Figure 6)

Installation date: July 22, 2009

Existing pipe: 42 in diameter CMP (invert rusted away)

Average trench width: 10 ft

Average trench depth: 7 ft

Bedding material: No. 57 stone (approximately 6 in)

Backfill material: No. 26 crusher run

Average final height of cover at the road centerline: 1.9 ft

Notes:

- There was no backfill compaction. Hand-operated compactors were not used.
- Surface compaction was carried out using Gradall Series 4100 excavator with rubber tires.



Figure 6. Installation of 48-inch Pipe at Route 635

- The entire 33.5-ft-long pipe run was assembled outside the trench and then lowered in position using multiple supporting chains attached to a Gradall bucket.
- Backfill stone was piled on top of the pipe to hold it in place.
- Riprap stone was hand placed around the pipe at each end.
- Observed defects were two puncture marks at 20 ft downstream caused by handling.

5. Route 698: 48-in-diameter, triple-wall pipe, 31 ft 2 in long (Figure 7)

Installation date: August 5, 2009

Existing pipe: 42-in-diameter CMP (invert rusted away)

Average trench width: 13 ft

Average trench depth: 7 ft

Bedding material: No. 57 stone (approximately 6 in)

Backfill material: No. 26 crusher run

Average final height of cover at the road centerline: 2.4 ft

Notes:

- There was no backfill compaction. Hand-operated compactors were not used.
- The trench was very wet and difficult to de-water.
- There were some large rocks in the trench soil approximately 12 in away from the pipe.
- Initially, compaction was carried out using Gradall Series 4100 excavator. It broke down during construction. The remaining backfill was compacted with a rubber tire backhoe.
- Pipes were joined in the trench. A pipe section was pushed into a partially backfilled pipe section with a Gradall bucket. Placement of pre-assembled pipes was not possible at this site because of the proximity of a telephone line).
- Backfill stone was piled on top of the pipe to hold it in place.
- Riprap stone was hand placed around the pipe at each end.
- No defects were observed.



Figure 7. Installation of 48-inch Pipe at Route 698

Summary

All pipe installations satisfied the minimum depth of cover requirement of 1 ft and minimum trench widths of 4.7 ft and 6.7 ft for 30-in and 48-in pipes, respectively, as recommended by ADS. With regard to compaction, none of the sites was compacted in accordance with VDOT specifications, mainly because of the unavailability of the necessary compaction equipment and the need to reopen the road quickly. Further, the placement of riprap stone directly in contact with the pipe is not recommended by ADS.

Field Evaluation of Installed Pipes

Comprehensive project records, including spreadsheets, photographs, and video inspections, are available from the Virginia Transportation Research Council's Matrix website.³⁵ [Free Google Earth software is required for viewing the "kmz" file.] Figures 8 through 12 show all pipes after 1 year of service. Photographs were taken during the final inspection on August 9, 2010.



Figure 8. View of 48-inch Pipe at Route 684 After 1 Year in Service



Figure 9. View of 30-inch Pipe at Route 736 After 1 Year in Service



Figure 10. View of 30-inch Pipe at Route 635 After 1 Year in Service



Figure 11. View of 48-inch Pipe at Route 635 After 1 Year in Service



Figure 12. View of 48-inch Pipe at Route 698 After 1 Year in Service

Pipe Deflections After 1 Year in Service

All linear measurements were taken downstream.

Average Deflections

1. *Route 684: 48-inch, triple-wall pipe: H = 0.3 percent, V could not be measured because of sediment accumulation*
2. *Route 736: 30-in, dual-wall pipe: H = 0.3 percent, V = 1.8 percent*
3. *Route 635: 30-in, dual-wall pipe: H = 0.6 percent, V = 2.4 percent*
4. *Route 635: 48-in, triple-wall pipe: H = 0.4 percent, V = 2.5 percent*
5. *Route 698: 48-in, triple-wall pipe: H = 0.4 percent, V = 1.7 percent.*

Maximum Deflections

1. *Route 684: 48-in, triple-wall pipe: H = 1.6 percent at 55 ft*
2. *Route 736: 30-in, dual-wall pipe: V = 3.3 percent at 25, 30, and 35 ft*
3. *Route 635: 30-in, dual-wall pipe: V = 4.6 percent at 5 ft*
4. *Route 635: 48-in, triple-wall pipe: V = 4.5 percent at 20 and 25 ft*
5. *Route 698: 48-in, triple-wall pipe: V = 2.9 percent at 12.5 and 20 ft*

Joint Gaps After 1 Year in Service

All joints were of the bell and spigot type. Gaps were measured inside the pipe at the ends of each section. Gaps do not indicate open joints. All linear measurements were taken downstream.

1. *Route 684: 48-in, triple-wall pipe:* 0.25 in gap detected at 20 ft after 120 days
2. *Route 736: 30-in, dual-wall pipe:*
 - *Initial:* 0.5-in gap all around at 20 ft, 1 in gap all around at 40 ft.
 - *Final:* 0.63-in joint gap right, 0.5-in joint gap left at 20 ft, 1-in gap all around at 40 ft.
3. *Route 635: 30-in, dual-wall pipe:*
 - *Initial:* 0.25-in gap all around at 10 ft
 - *Final:* 0.5-in gap all around at 10 ft.
4. *Route 635: 48-in, triple-wall pipe:*
 - *Initial:* no gap at 5 ft, 0.63-in bottom gap and 0.25-in side gap at 25 ft
 - *Final:* 0.25-in gap right, 0.13-in gap left at 5 ft, 0.5-in side gap and 1-in bottom gap at 25 ft.
5. *Route 698: 48-in, triple-wall pipe:*
 - *Initial:* no gap at 10 ft; at 30 days, 0.75-in bottom gap
 - *Final:* 0.38-in gap left, 0.5-in gap right.

Defects

No new defects were discovered, and no progression of the original defects was detected after 1 year of monitoring. In addition, no signs of joint infiltration were observed. Pipe alignment remained satisfactory. All pipes were fully functional. All pipes would satisfy current VDOT post-installation inspection requirements implemented in July 2010 through a revised Section 302 of VDOT's *Road and Bridge Specifications*. These requirements were not in place at the time of installation.

DISCUSSION

Weather conditions were severe in Virginia in the early part of 2010, resulting in substantial precipitation and unusually low ambient air temperatures. Typically, this is a challenging environment for any type of drainage structure. Based on visual observations and cross-sectional measurements, it appears that all ADS polypropylene pipes performed

satisfactorily in the first year of service. The recorded deflections were below 5 percent. No evidence of crack propagation, crushing, or buckling was detected. All sites would have passed post-installation inspection as specified in the recently revised Section 302 of VDOT's *Road and Bridge Specifications*. All pipes were found to be fully functional.

It should be noted that all polypropylene pipes performed with a low height of cover of approximately 2 ft. As a consequence, the resulting confining stresses were relatively small although the impact loads may have been substantial. The manufacturer stipulated the maximum height of cover of 32 ft and 24 ft for 30-in and 48-in pipes, respectively, with a well-compacted Class I backfill material. None of the pipes monitored in this study provided the opportunity to observe the pipe behavior with a height of cover approaching the maximum allowable value.

Despite the previously discussed compaction issues regarding the installation, no excessive deformations were found in any polypropylene pipe after 1 year in service. Maximum recorded deflections were approximately 4.5 percent of the nominal diameter. This is indicative of the relatively high pipe stiffness that the polypropylene material provides.

At present, polypropylene pipes can be used on the VDOT network only for testing purposes; they undergo periodic visual inspections combined with cross-sectional measurements. This course of action will allow VDOT personnel to gain more practical experience with the product, but it is unlikely to resolve the issue of durability in the near future. Although the pipes delivered a satisfactory service during the first year of operation, the field performance to date cannot be used to extrapolate the pipe design life with a reasonable degree of confidence. Short-term visual monitoring will not detect the onset of degradation and the loss of mechanical properties. Alternatively, a new VDOT specification based on extensive laboratory testing can be developed to allow polypropylene pipes from various manufacturers to be evaluated and potentially considered as a viable option on transportation projects.

Currently, VDOT specifies a minimum service life of 50 years for pipes in the "Lower Functional Roadway Classification" and 75 years for pipes under the "Higher Functional Roadway Classification" as shown in Tables A (Allowable Type of Pipe Culvert) and A1 (Allowable Type of Storm Sewer Pipe) of sheets 107.21 and 107.22 of the R&B Standard PC-1. The latest AASHTO Load and Resistance Factor Design (LRFD) guidelines specify a minimum design life of 75 years for bridges; therefore, a similar time frame for design life should also be considered for some drainage pipes.

The use of plastic materials in civil engineering construction dates back to the late 1950s and has become increasingly popular in the past 30 years. Typical applications include geomembranes used to line landfills for groundwater protection and geogrids used as reinforcing elements of mechanically stabilized earth walls. These applications are normally expected to perform for decades, and the issue of durability of the plastic component becomes extremely important. Recent advances in material science, test methods, and refined production techniques provide engineers with a variety of scientific tools to assess the long-term behavior with a reasonable degree of confidence. The use of polymers, including polypropylene, in mechanically stabilized earth wall systems is presently considered a routine practice in civil engineering. These structures are typically designed for a service life of 75 years and more,

based on the knowledge acquired from extensive research on the long-term material properties. It may be feasible to adapt the test methods originally developed for geosynthetics to polypropylene pipes.

Although a number of test methods potentially applicable to polypropylene materials have been developed, currently there is no comprehensive national standard in the United States for acceptance of polypropylene pipe products. Presently, various state DOTs individually determine the conditions for product adoption on their respective transportation system.

CONCLUSIONS

- *The handling and installation of polypropylene plastic drainage pipes do not require any special construction skills or equipment.*
- *The process of connecting pipes together outside the trench and then lowering the entire assembly using multiple support points is quick and efficient. The entire pipe assembly remained rigid during placement, and no damage to pipes and joints occurred.*
- *Placement of loose backfill material on top of the pipe in the trench minimized lateral displacements during backfill by weighing down and stabilizing the entire pipe run.*
- *Despite the suboptimal backfill compaction, polypropylene plastic pipes performed satisfactorily during the first year in service. Cross-sectional deflections remained within allowable limits, joint displacements were minimal, and no evidence of progressive material failure was detected during the monitoring period. The pipes remain in service and are available for future inspections.*
- *The literature indicates that the chemical makeup of plastic pipe products is highly complex and often proprietary. The type and amount of additives can drastically affect the material's physical behavior and service life. Oxidation and UV-induced weathering are the primary mechanisms of degradation of polypropylene, affecting its durability.*

RECOMMENDATIONS

1. *In the absence of a nationally recognized U.S. standard explicitly addressing the durability of polypropylene plastic pipes, VDOT's Materials Division should implement a two-stage approval protocol, as follows:*

Provisional approval shall be granted for the procurement of polypropylene pipes, joints, and gaskets that conform to the requirements of ASTM F2736 or ASTM F2764, depending on the applicable diameter, with the following additional requirements:

- All material testing relevant to the long-term performance assessment shall be conducted by an independent third party laboratory accredited to perform such tests.
- Long-term material performance testing shall be performed on samples obtained from a finished pipe product and shall include creep, chemical degradation, and weathering.
- Creep testing shall comply with the requirements of WSDOT Standard Practice T 925 (Standard Practice for Determination of Long-term Strength for Geosynthetic Reinforcement), including the methodology outlined in Appendix B (Creep Rupture Testing and Extrapolation Procedures) and Appendix C (Strain Based Creep Testing and Extrapolation) of WSDOT Standard Practice T 925.
- UV degradation resistance shall be tested in accordance with ASTM D4355 or DIN EN 12224.
- Oxidation resistance shall be determined in accordance with one of the following standards: ASTM D3895, ASTM D5885, or ISO 13438.
- The application for the approval of a new polypropylene pipe product shall be submitted to the Department by a registered Professional Engineer and shall include a report presenting a summary and an interpretation of test results. For each size of each material type, the report shall contain estimates of service life when the pipe is used in culvert and storm sewer applications. It shall also include estimated design values of tensile modulus and flexural modulus for the projected service life of the pipe, in addition to the corresponding short-term design values.

Final approval for culvert and storm sewer applications shall be granted for polypropylene pipes that have been provisionally field tested on the Department's network for a minimum of one year duration. Field verification shall be required for each size of each pipe material/resin. Final approval shall be granted only if the results of the final inspection are in a substantial agreement with the results of the post-installation inspection. .

These requirements may be waived by the Department if the supplier can document the particular product's formal, routine, and ongoing acceptance on a foreign transportation network based on a universally recognized methodology. Examples include, but are not limited to, national standards developed by TRL (U.K.), BAST (Germany), and LCPC (France). The acceptance of a foreign standard would be based on the Department's assessment of its applicability and relevance to the transportation network in Virginia.

2. *VDOT's Area Construction Engineer should reject any polypropylene pipe that is mechanically damaged during handling and installation. Currently, there is no viable technique to assess the long-term consequence of a localized defect.*

BENEFITS AND IMPLEMENTATION PROSPECTS

The results of the study indicate that polypropylene pipe offers a number of potential benefits when used in drainage applications. It is lightweight and easy to handle, assemble, and install. It does not require any specialized equipment or methods during construction. It appears to be rigid enough to tolerate some deviations from the commonly mandated backfill procedures and still perform satisfactorily. No signs of excessive deformation were observed during the study period. The chemical makeup renders it attractive to consider for use in highly acidic and highly alkaline environments. Its double seal design reduces the risk of a joint leakage. When tested at Route 698, it showed no evidence of wear and erosion from a relatively high water flow combined with the substantial presence of large rock particles. Each of these potential benefits warrants further consideration of using a polypropylene pipe in the transportation infrastructure.

The durability of a plastic pipe is a matter that must be resolved adequately in order to facilitate widespread product usage. In the case of polypropylene pipe, the issue of degradation because of material oxidation is extremely important. For many transportation projects, the

owner must have a reasonable degree of assurance that the material will perform satisfactorily for at least 50 years. Fortunately, there are test methods currently available, including the ones specified in the recently published ASTM standards, for the durability assessment. It is possible that as users become more familiar with polypropylene pipe, they will increasingly regard it as a viable alternative in terms of life cycle costs. The product appears to lend itself to further evaluation as a promising innovative design.

ACKNOWLEDGMENTS

The author expresses his appreciation to the VDOT Pipe and Drainage Committee for providing valuable comments and suggestions. Crews of VDOT's Charlottesville Residency and Yancey Mills Area Headquarters carried out project logistics and all construction activities. Mr. Arthur Wagner of VCTIR provided project coordination and assisted with field data collection. Mr. Timothy Edwards of ADS was instrumental in acquiring all field measurements. Ms. Barbara Neyman supplied the reference material. Mr. Ken Winter assisted with the literature search. Ms. Linda Evans of VCTIR provided assistance with the editorial process.

REFERENCES

1. Borealis Group. BorECO PP pipe materials—made for generations. http://www.borealisgroup.com/pdf/literature/borealis-borouge/brochure/IN0111_GB_PF_2008_01_BB. Accessed March 14, 2011.
2. ADS, Inc. ADS Inc. Drainage Handbook: ADS SaniTite HP 12"-30" Pipe Specifications. May 2010. http://www.ads-pipe.com/pdf/en/ADS_SaniTite_HP_12-30_Pipe_Specification.pdf. Accessed February 8, 2011.
3. ADS, Inc. ADS Inc. Drainage Handbook: ADS SaniTite HP 30"-60" Pipe Specifications. http://www.ads-pipe.com/pdf/en/ADS_SaniTite_HP_30-60_Pipe_Specification.pdf. May 2010. Accessed February 8, 2011.
4. ADS, Inc. Minimum and Maximum Cover Heights for SaniTite® HP Pipe for Sanitary Sewer. ADS Technical Note TN 2.05. February 2010. http://www.ads-pipe.com/pdf/en/A2.05-Min-Max_Cover_Heights_for_SaniTite_HP.pdf. Accessed February 8, 2011.
5. ADS, Inc. Chemical Resistance of Polypropylene and Elastomers. ADS Technical Note TN 4.02. October 2009. http://www.ads-pipe.com/pdf/en/A4.02-Chemical_Resistance_PP-Elastomers.pdf. Accessed February 8, 2011.
6. Advanced Drainage Systems, Inc. Abrasion Resistance of Polypropylene. ADS Technical Note TN 4.03. February 2010. <http://www.ads->

- pipe.com/pdf/en/A4.03_Abrasion_Resistance_of_Polypropylene.pdf. Accessed February 8, 2011.
7. ADS, Inc. Drainage Handbook—Hydraulics. <http://www.ads-pipe.com/pdf/en/ADH3-Hydraulics.pdf>. Accessed February 8, 2011.
 8. ADS, Inc. Drainage Handbook—Structures. <http://www.ads-pipe.com/pdf/en/ADH2-Structures.pdf>. Accessed February 8, 2011.
 9. Janson, L.E. *Plastic Pipes for Water Supply and Sewage Disposal*. Borealis, Stockholm, Sweden, 1996.
 10. Maier, C., and Calafut, T. *Polypropylene: The Definitive User's Guide and Databook*. Plastics Design Library, Norwich, N.Y., 1998.
 11. Kay, D., and Blond, E. *A Guide to Assess the Durability of 'Plastic' Materials Used in Civil Engineering*. 6th Transportation Specialty Conference, Toronto, Ontario, Canada, June 2-4, 2005.
 12. ASTM International. *ASTM Standard G166: Standard Guide for Statistical Analysis of Service Life Data*. West Conshohocken, Pa., 2005.
 13. ASTM International. *ASTM Standard G169: Standard Guide for Application of Basic Statistical Methods to Weathering Tests*. West Conshohocken, Pa., 2008.
 14. ASTM International. *ASTM Standard G172: Standard Guide for Statistical Analysis of Accelerated Service Life Data*. West Conshohocken, Pa., 2010.
 15. ASTM International. *ASTM Standard G7: Standard Practice for Atmospheric Environmental Exposure Testing of Nonmetallic Materials*. West Conshohocken, Pa., 2005.
 16. Hsuan, Y.G., Schroeder, H.F., Rowe, K., Müller, W., Greenwood, J., Cazzuffi, D., and Koerner, R.M. *Long-Term Performance and Lifetime Prediction of Geosynthetics*. EuroGeo4, Edinburgh, Scotland, U.K., September 7-10, 2008.
 17. ASTM International. *ASTM Standard D3895: Standard Test Method for Oxidative-Induction Time of Polyolefins by Differential Scanning Calorimetry*. West Conshohocken, Pa., 2007.
 18. ASTM International. *ASTM Standard D5885: Standard Test Method for Oxidative Induction Time of Polyolefin Geosynthetics by High-Pressure Differential Scanning Calorimetry*. West Conshohocken, Pa., 2006.
 19. International Organization for Standardization. *Geotextiles and Geotextile-Related Products: Screening Test Method for Determining the Resistance to Oxidation*. ISO 13438. Geneva, Switzerland, 2004.

20. ASTM International. *ASTM Standard D4355: Standard Test Method for Deterioration of Geotextiles by Exposure to Light, Moisture and Heat in a Xenon Arc Type Apparatus*. West Conshohocken, Pa., 2007.
21. German Institute for Standardization. *DIN EN 12224: Geotextiles and Geotextile-Related Products: Determination of the Resistance to Weathering*. Berlin, 2000.
22. Hsuan, Y.G., and Koerner, R.M. Antioxidant Depletion Lifetime in High Density Polyethylene Geomembranes. *Journal of Geotechnical and Geoenvironmental Engineering*, June 1998, pp. 532-541.
23. Elias, V., DiMaggio, J.A., and DiMillio, A. FHWA Technical Note on the Degradation-Reduction Factors for Geosynthetics. *Geotechnical Fabrics Report*, Vol. 15, No. 6, August 1997, pp. 24-27.
24. European Committee for Standardization. *BS EN 13476-3: Plastics Piping Systems for Non-Pressure Underground Drainage and Sewerage: Structured-Wall Piping Systems of Unplasticized Poly(Vinyl Chloride) (PVC-U), Polypropylene (PP) and Polyethylene (PE)*. , Brussels, 2009.
25. ASTM International. *ASTM Standard D6992: Standard Test Method for Accelerated Tensile Creep and Creep-Rupture of Geosynthetic Materials Based on Time-Temperature Superposition Using the Stepped Isothermal Method*. West Conshohocken, Pa., 2009.
26. ASTM International. *ASTM Standard D2990: Standard Test Methods for Tensile, Compressive, and Flexural Creep and Creep-Rupture of Plastics*. West Conshohocken, Pa., 2009.
27. ASTM International. *ASTM Standard D5262: Standard Test Method for Evaluating the Unconfined Tension Creep and Creep Rupture Behavior of Geosynthetics*. West Conshohocken, Pa., 2007.
28. Lothspeich, S.E., and Thornton, J.S. Comparison of Different Long Term Reduction Factors for Geosynthetic Reinforcing Materials. In *Proceedings of the Second European Geosynthetics Conference, EuroGeo 2*, Bologna, Italy, 2000, pp. 341-346.
29. Washington State Department of Transportation. WSDOT Standard Practice T 925: Standard Practice for Determination of Long-Term Strength for Geosynthetic Reinforcement. In *Washington State Department of Transportation Materials Manual*. Olympia, 2009. <http://www.wsdot.wa.gov/publications/manuals/fulltext/M46-01/Materials.pdf>. Accessed February 8, 2011.
30. International Organization for Standardization. *ISO 20432: Guidelines for the Determination of the Long-Term Strength of Geosynthetics for Soil Reinforcement*. Geneva, 2007.

31. Elias, V., Fishman, K.L., Christopher, B.R., and Berg, R.R. *Corrosion/Degradation of Soil Reinforcements for Mechanically Stabilized Earth Walls and Reinforced Soil Slopes*. FHWA-NHI-00-044. Ryan R. Berg & Associates, Woodbury, Minn., 2009.
32. McGrath, T.J., Moore, I.D., and Hsuan, Y.G. *Updated Test and Design Methods for Thermoplastic Drainage Pipe*. NCHRP Report 631. Transportation Research Board of the National Academies, Washington, D.C., 2009.
33. ASTM International. *ASTM Standard F2736: Standard Specification for 6 to 30 in. (152 to 762 mm) Polypropylene (PP) Corrugated Single Wall Pipe and Double Wall Pipe*. West Conshohocken, Pa., 2010.
34. ASTM International. *ASTM Standard F2764: Standard Specification for 30 to 60 in. (750 to 1500 mm) Polypropylene Triple Wall Pipe and Fittings for Non-Pressure Sanitary Sewer Applications*. West Conshohocken, Pa., 2010.
35. Virginia Transportation Research Council. Matrix: Index of /ADS_PP. http://matrix.vtrc.virginia.edu/ADS_PP/. Accessed March 21, 2011.