This study was sponsored by the South Carolina Department of Transportation and the Federal Highway Administration. The opinions, findings and conclusions expressed in this report are those of the authors and not necessarily those of the SCDOT or FHWA. This report does not comprise a standard, specification or regulation.

SPECIFICATIONS FOR CULVERT PIPE USED IN SCDOT HIGHWAY APPLICATIONS

SARAH L. GASSMAN, PH.D.

SUBMITTED TO
THE SOUTH CAROLINA DEPARTMENT OF TRANSPORTATION
AND
THE FEDERAL HIGHWAY ADMINISTRATION

OCTOBER 2005
(Revised March 2006)
This report presents the findings from a study undertaken to improve the field performance and service life of reinforced concrete, aluminum alloy and high density polyethylene culvert pipe used in SCDOT roadway applications. The work resulted in the development of a “SCDOT Culvert Pipe Selection Guide” which provides a step by step procedure for selecting pipe materials for specific applications. The criteria for pipe selection include durability, hydraulic capacity, structural capacity, service life, compatibility of pipe material to site conditions and life cycle costs. Guidance is provided on the recommended practices for proper design, installation and quality control/quality assurance for product approval and field inspection of delivered pipe and installation procedures. Recommendations were made to modify the SCDOT Standard Specifications for Highway Construction and other SCDOT documents to properly address the design, installation and inspection of culvert pipe. The final product of this work was the development of a training course to educate SCDOT personnel on the proper design, installation, maintenance, and quality control/quality assurance of culvert pipe used in roadway applications.
The content of this report reflects the views of the authors who are responsible for the findings and conclusions presented herein. The contents of this report do not necessarily reflect the views of the South Carolina Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification or regulation.
ACKNOWLEDGEMENTS

This research was funded by the South Carolina Department of Transportation and the Federal Highway Administration. Their support is greatly appreciated. The author would like to acknowledge the following students for their contribution to this investigation: Evangelia Leon, Chetana Kommireddi, Erin Atkins, and Shanna Neill.
EXECUTIVE SUMMARY

This report presents the findings from a study undertaken to improve the field performance of culvert pipe used in SCDOT roadway applications. Reinforced concrete, corrugated aluminum alloy and high density polyethylene pipe are the primary pipe materials used on SCDOT projects. Appropriate use of these pipe materials in terms of design, installation, maintenance, service life, and quality control/quality assurance was the focus of the study. The research involved reviewing research manuscripts, AASHTO and ASTM specifications, construction standards and specifications of state transportation departments, and manufacturer’s literature. The work resulted in the development of a “SCDOT Culvert Pipe Selection Guide” which provides a step by step procedure for selecting pipe materials for specific applications. The criteria for pipe selection include durability, hydraulic capacity, structural capacity, service life, compatibility of pipe material to the environmental site conditions and life cycle costs. Guidance is provided on the recommended practices for materials, materials management, installation (backfill materials, trenching, bedding, laying pipe, backfilling, and cover heights), design, maintenance, quality control/quality assurance for product approval and field inspection of delivered pipe and installation procedures. Recommendations made to improve the installation of all culvert pipe include improving the quality and density of backfill materials placed around pipe, improving the compaction inspection standards by performing density checks on compacted backfill at the spring line of the pipe to ensure that compaction is adequate in the haunches, requiring a minimum compaction level of 95% Standard Proctor density, and requiring all pipe to meet minimum cover requirements. Recommendations made to improve the inspection standards for all installed pipes include visually inspecting all pipes after installation to ensure proper joining, line and grade of pipe. Large diameter pipe should be inspected by walking the length of the pipe; whereas small diameter pipes require the use of video camera equipment with a laser deflection measuring device attached. Random inspections of pipe should be made throughout the construction process to prevent poor construction methods from propagating through entire projects. The study also recommends utilizing third party certification and testing programs for quality control and quality assurance. The final product of this work was the development of a training course to educate SCDOT personnel on the proper design, installation, maintenance, and quality control/quality assurance of culvert pipe used in roadway applications.
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<th>APPROPRIATE CONVERSIONS FROM SI UNITS</th>
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<tr>
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<td><strong>When You</strong></td>
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<tr>
<td><strong>LENGTH</strong></td>
<td></td>
</tr>
<tr>
<td>In</td>
<td>inches</td>
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<tr>
<td>Ft</td>
<td>feet</td>
</tr>
<tr>
<td>Yd</td>
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<td>Mi</td>
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<tr>
<td><strong>AREA</strong></td>
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</tr>
<tr>
<td>in²</td>
<td>square inches</td>
</tr>
<tr>
<td>ft²</td>
<td>square feet</td>
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<tr>
<td>yd²</td>
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</tr>
<tr>
<td>mi²</td>
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</tr>
<tr>
<td><strong>VOLUME</strong></td>
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</tr>
<tr>
<td>fl oz</td>
<td>fluid ounces</td>
</tr>
<tr>
<td>Gal</td>
<td>gallons</td>
</tr>
<tr>
<td>ft³</td>
<td>cubic feet</td>
</tr>
<tr>
<td>yd³</td>
<td>cubic yards</td>
</tr>
<tr>
<td><strong>NOTE</strong>: Volumes greater than 1000 l shall be shown in m³</td>
<td></td>
</tr>
<tr>
<td><strong>MASS</strong></td>
<td></td>
</tr>
<tr>
<td>Oz</td>
<td>ounces</td>
</tr>
<tr>
<td>Lb</td>
<td>pounds</td>
</tr>
<tr>
<td>T</td>
<td>Short tons (2000 lb)</td>
</tr>
<tr>
<td><strong>TEMPERATURE (exact)</strong></td>
<td></td>
</tr>
<tr>
<td>°F</td>
<td>Fahrenheit</td>
</tr>
<tr>
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<tr>
<td>Fc</td>
<td>foot-candles</td>
</tr>
<tr>
<td>Fl</td>
<td>foot-Lamberts</td>
</tr>
<tr>
<td><strong>FORCE and PRESSURE or STRESS</strong></td>
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</tr>
<tr>
<td>Lbf</td>
<td>poundforce</td>
</tr>
<tr>
<td>lbf/in²</td>
<td>poundforce per square inch</td>
</tr>
</tbody>
</table>

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E38.*
1.0 Introduction

This report presents the findings from a study undertaken to improve the field performance of culvert pipe used in SCDOT roadway applications. Reinforced concrete (RCP), corrugated aluminum alloy (CAAP) and high density polyethylene (HDPE) pipe are the primary pipe materials used on SCDOT projects. Appropriate use of these pipe materials in terms of design, installation, maintenance, service life, and quality control/quality assurance was the focus of the study.

1.1 Background

Although corrugated high density polyethylene (HDPE) pipe has been used successfully for decades in a variety of drainage applications, it is relatively new when compared to concrete and aluminum pipe. With all three products having similar hydraulic performance, selection of the pipe material for a project will be based on considerations other than hydraulics, such as strength, durability and cost.

Not much was known about the field performance of HDPE pipe in South Carolina prior to the SCDOT study entitled “Performance of High Density Polyethylene (HDPE) Pipe” (Gassman et al. 2000). The study (herein referred to as “Phase I”) presented results from field investigations of 45 HDPE pipes, primarily used in sideline or driveway applications, throughout South Carolina that were conducted to evaluate both the external and internal pipe conditions. Overall the pipes were performing well, maintaining a relatively round shape with limited structural distress, and were still functioning as originally intended. As such, the study found that HDPE pipe is an acceptable pipe material that can be used on SCDOT maintenance and construction projects when proper installation techniques are followed.

Some pipes inspected in the Phase I study had cracks, localized bulges and excess deformations, yet none of the damage was severe enough to require removal and replacement at the time of investigation. It was clear from the study that the performance of the pipe was significantly influenced by the installation technique. Installation problems such as poor preparation of bedding soils, inappropriate backfill material, and inadequate backfill cover contributed to the excessive deflection and observed internal cracking in pipes with noted damage. Appropriate installation procedures are essential to achieving high quality performance. Therefore, the study recommended the following to improve the performance of HDPE pipe in South Carolina: train maintenance crews in the laying of plastic pipe, follow ASTM and AASHTO installation procedures, inspect pipes after installation, and develop guidelines for HDPE pipe product approval.

In the past few years, the results of many state, federal and industry supported research projects have led to recent changes to AASHTO specifications (AASHTO M294, Section 12 of the AASHTO LRFD Bridge Design Specifications, Section 18 of the Standard Specifications for Highway Bridges, and Section 30 of the Construction Section of both the Standard Specifications for Highway Bridges and the LRFD Bridge Design Specifications). These changes have been made to improve standard design and installation practices as well as material requirements for HDPE pipe. In addition, many state transportation departments have made significant changes to their construction specifications and standards for culvert pipe, and have also updated their drainage manuals.
Even today the subject of culvert pipe performance still remains one of great importance in the transportation community because of the need to improve the performance of all pipe materials used in drainage applications. Koerner (2004), in his paper written for the TRB Transportation in the New Millennium paper, indicated that there are many issues that are still unanswered and need to be researched. Some of these include:

How to guarantee acceptable drainage during a service lifetime? What maintenance commitments and training are needed to ensure adequate performance? How to formulate specifications to ensure the adequacy of specific products and materials? How to best define and quantify life-cycle costs and subsequent performance? While the results of this study and studies by others are beginning to answer these questions, future research is necessary to fully understand how to design and install culvert pipe to achieve optimum performance, and how to guarantee the projected service life. Therefore, it is recommended that the SCDOT consider the recommendations and guidance in this report and implement as deemed necessary. Then, they should engage in a continuous mode of improvement by updating and revising construction standards, specifications, manuals, etc. as the results of future research become available.

1.2 Objective

The overall objective of this work was to provide guidance for SCDOT engineers and maintenance personnel in design, installation, maintenance, and quality control/quality assurance of culvert pipe used in roadway applications. Currently, the SCDOT approves three pipe materials for use in its highways. They are reinforced concrete, aluminum alloy and HDPE pipe which were the focus of the study.

To meet this objective the following work was performed:

1) Reviewed research manuscripts, AASHTO and ASTM specifications, construction standards and specifications used by transportation departments, and manufacturer’s literature on topics including design, installation, maintenance, durability, service life and quality control/quality assurance of reinforced concrete, aluminum and HDPE pipe.

2) Developed a “SCDOT Culvert Pipe Selection Guide” which provides a step by step procedure for selecting pipe materials for specific applications. The criteria for pipe selection include durability, hydraulic capacity, structural capacity, service life, and compatibility of pipe material to site conditions.

3) Provided guidance on the recommended practices for proper design and installation of reinforced concrete, high density polyethylene and aluminum alloy culvert pipes; including guidance for materials, materials management, installation (backfill materials, trenching, bedding, laying pipe, backfilling, and cover heights), installation inspection, and maintenance.

4) Made recommendations to modify the SCDOT Standard Specifications for Highway Construction to properly address the design and installation of concrete, aluminum and HDPE culvert pipe.
5) Provided guidance for quality control/quality assurance for product approval and material testing and quality control/quality assurance for field inspection of delivered pipe and installation procedures.

6) Evaluated life cycle cost methodology.

7) Developed training/certification courses to educate SCDOT personnel on the proper design, installation, maintenance and quality control/quality assurance of culvert pipe used in roadway applications.

1.3 REPORT OUTLINE

This report is divided into seven sections. Following the brief introduction presented here in Section 1, the “SCDOT Culvert Pipe Selection Guide” is presented in Section 2. The guide outlines a step by step procedure to select the appropriate pipe type(s) for a given project. The evaluation of a pipe material is based on durability, hydraulic capacity, structural capacity, and life cycle cost. Section 3 contains the recommended practices for proper design and installation of reinforced concrete, high density polyethylene and aluminum alloy culvert pipe. Guidance is provided for materials, materials management, installation (backfill materials, trenching, bedding, laying pipe, backfilling, and cover heights), installation inspection, and maintenance. Section 4 presents a summary of the third party certification programs recommended for culvert pipe approval. Section 5 presents an overview of life cycle cost analysis. A summary of the training course objectives and course outlines are presented in Section 6. Finally, the findings of the study are summarized in Section 7. Recommended revisions to Section 714 of the SCDOT Standard Specifications for Highway Construction are provided.
2.0 CULVERT PIPE SELECTION GUIDE

This section contains the recommended pipe usage guide developed in this study for the SCDOT. The “SCDOT Culvert Pipe Selection Guide” was developed based on usage guides from Florida, Georgia, North Carolina, Virginia, West Virginia, Maryland, Utah, Missouri, Kentucky and others.

The guide outlines a step by step procedure to select the appropriate pipe type(s) for a given project. The first step is to determine all the acceptable pipe material types based on use and design life. Next, a hydraulic analysis is performed to estimate required pipe diameter for each acceptable pipe material type. Once the acceptable pipe material types have been determined, then corrosion and abrasion analyses are performed for the estimated pipe diameter based on the environmental conditions (pH, resistivity, chlorides and sulfates) of the soil and water found at the site. Flow velocity is also considered for abrasion resistance. This analysis will result in a list of acceptable pipes that meet environmental service life requirements. The hydraulic analysis is again performed on this new list of acceptable pipes to confirm the diameter estimate in the event that the corrosion and abrasion analyses changed the initial diameter estimates or eliminated one or more of the acceptable pipe material types. The next step is to perform a structural analysis and verify that the depth of backfill is in between the recommended minimum and maximum fill heights. Minimum and maximum cover height tables are included in the guide. The final step is to analyze life cycle costs.

It is important to note that Section 5514 “Competition for Specification of Alternative Types of Culvert Pipes” of the Code of Federal Regulations requires that “…States provide for competition with respect to the specification of alternative types of culvert pipes through requirements that are commensurate with competition requirements for other construction materials.…”. The guide presented herein outlines a procedure to help meet this federal requirement.
SCDOT CULVERT PIPE SELECTION GUIDE

The evaluation of a pipe material is based on durability, hydraulic capacity, structural capacity, and life cycle cost.

Methodology:

1) Determine acceptable pipe material types based on use and design life.
2) Perform hydraulic analysis to estimate required pipe diameter for each acceptable pipe type.
3) Perform corrosion and abrasion analysis for the estimated pipe diameter based on environmental conditions of soil and water.
4) Obtain list of acceptable pipes that meet environmental service life requirements.
5) Perform hydraulic analysis to confirm diameter estimate.
6) Perform structural analysis. Verify that depth of backfill meets the minimum and maximum fill height requirements.
7) Analyze life cycle costs.

ACCEPTABLE PIPE MATERIAL TYPES BASED ON USE AND DESIGN LIFE:

The first step is to determine the allowable culvert pipe materials for a given design classification or location using Table 1. The overall service life of a pipeline is a function of the pipe material, the environmental site conditions and the installation of the pipe. The material properties of the pipes on this list meet the desired service life requirements as noted in the table. Further analysis is required to determine if these pipes meet the environmental service life requirements as outlined in Step 3. In addition, analysis should consider the recommended minimum backfill soil conditions noted in Table 1.

The pipe material requirements (size limits and material specifications) for each pipe type are shown in Table 2.

HYDRAULICS:

The second step is to perform hydraulic analysis to estimate the required pipe diameter for each acceptable pipe material type. The designer should use Table 2 when assigning a Manning’s “n” value for the various culvert pipe options allowed for a given roadway classification. Recommended design values should be used unless the engineer has a justifiable reason for selecting a different value from the range of acceptable values. If more than one material type is acceptable for a given project, more than one hydraulic design may be required: one using a Manning’s roughness coefficient (n=0.13) associated with concrete, spiral rib, and polyethylene pipe and one using a Manning’s roughness coefficient associated with corrugated aluminum alloy pipe.
Table 1. Allowable Culvert Pipe Materials for a Given Design Classification/Location

<table>
<thead>
<tr>
<th>PROJECT FUNCTIONAL CLASS¹</th>
<th>DESIGN CLASSIFICATION/LOCATION (EXPECTED SERVICE LIFE)²</th>
<th>ALLOWABLE PIPE MATERIALS</th>
</tr>
</thead>
</table>
| “Freeways”                | Cross drains under pavements, shoulder, or between curbs; parallel storm sewers under pavement or between curbs or median drains. (75 year service life) | • Circular reinforced concrete culvert pipe  
• Corrugated aluminum alloy culvert pipe  
• Spiral Rib aluminum pipe – Type IR  
• Corrugated high density polyethylene culvert pipe-Type S |
|                           | Storm sewers outside of pavements or curbs (50 year service life) | • all of the above  
• Elliptical reinforced concrete culvert pipe  
• Corrugated aluminum alloy culvert pipe arch |
| “Rural Highways” “Suburban/Urban Streets” “Local Roads and Streets” | Cross drains under pavements, shoulder, or between curbs; parallel storm sewers under pavement or between curbs or median drains (50 year service life) | • Circular reinforced concrete culvert pipe  
• Corrugated aluminum alloy culvert pipe  
• Spiral Rib aluminum pipe – Type IR  
• Corrugated high density polyethylene culvert pipe-Type S |
|                           | Storm sewers outside of pavements or curbs (50 year service life) | • all of the above  
• Elliptical reinforced concrete culvert pipe  
• Corrugated aluminum alloy culvert pipe arch |
|                           | Side drains and driveways - not under roadway (25 year service life) | • all of the above |
| Temporary Applications    | All of the above | • all of the above  
• Galvanized corrugated steel pipe  
• Corrugated high density polyethylene culvert pipe-Type C |

¹Project function class is defined by the SCDOT Highway Design Manual (2003).
²Expected service life is a function of 1) pipe material and 2) installation; therefore, as further discussed in Section 3.0.3.1, applications that require at least a 75 year service life (freeways) shall use a well-graded sand or gravel meeting the requirements of GW or SW material (ASTM 2487) or A-1 (AASHTO M 145) for the bedding and backfill. Uniformly graded coarse-grained soils (GP, SP and A-3) can be used if provisions are made to evaluate and control possible migration of fines into open voids. Backfill shall be compacted to at least 95% of maximum standard Proctor density per AASHTO T 99.

Conduits under roadways having a 50 year service life (rural highways, suburban and urban streets, local roads and streets) shall use the requirements for a 75 year service life or shall use coarse grained soils with fines or fine grained soils with at least 50% coarse grained material and low to no plasticity (GC, GM, SC, SM, A-2-4 and A-2-5) if compaction requirements are strictly enforced. Backfill shall be compacted to at least 95% of maximum standard Proctor density per AASHTO T 99.

Storm sewers outside of pavements (50 year service life) or applications that require a 25 year service life (side drains, driveways and conduits outside of pavements) may use any of the materials above as well as fine grained soils with low to medium plasticity (CL, ML, GC, SC or A-2-6, A-2-7, A-5, A-6) compacted to at least 95% of maximum standard Proctor density per AASHTO T 99.
<table>
<thead>
<tr>
<th>TYPE OF PIPE</th>
<th>SIZE LIMITS</th>
<th>DESIGN “n” VALUES (range)¹</th>
<th>MATERIAL SPECIFICATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circular reinforced concrete culvert pipe</td>
<td>15” to 144”</td>
<td>0.013 (0.010-0.015)</td>
<td>Use at least Class III pipe meeting AASHTO M 170.</td>
</tr>
<tr>
<td>Elliptical reinforced concrete culvert pipe</td>
<td>14” x 23” to 68” x 106”</td>
<td>0.013 (0.010-0.015)</td>
<td>Use at least Class III pipe meeting AASHTO M 207.</td>
</tr>
<tr>
<td>Corrugated High Density Polyethylene culvert pipe (HDPE)</td>
<td>12” to 60”</td>
<td>0.013 (0.010-0.015)</td>
<td>Use pipe meeting AASHTO M294. Use only Type S</td>
</tr>
<tr>
<td>Corrugated aluminum alloy culvert pipe w/ ½” deep corrugation (helical)²</td>
<td>12”-24”</td>
<td>0.015 (0.011-0.015)</td>
<td>Use at least 16 gage pipe meeting AASHTO M 196.</td>
</tr>
<tr>
<td>Corrugated aluminum alloy culvert pipe w/ 1” deep corrugation (helical)</td>
<td>30”-120”</td>
<td>0.022³ or 0.027⁴ (0.022-0.027)</td>
<td>Use at least 16 gage pipe meeting AASHTO M 196.</td>
</tr>
<tr>
<td>Corrugated aluminum alloy culvert pipe arch w/ ½” deep corrugation</td>
<td>17” x 13” to 71” x 47”</td>
<td>0.020 (0.012-0.022)</td>
<td>Use at least 16 gage pipe meeting AASHTO M 196.</td>
</tr>
<tr>
<td>Corrugated aluminum alloy culvert pipe arch w/ 1” deep corrugation</td>
<td>60” x 46” to 112” x 75”</td>
<td>0.027 (0.022-0.027)</td>
<td>Use at least 16 gage pipe meeting AASHTO M 196.</td>
</tr>
<tr>
<td>Spiral Rib aluminum pipe – Type IR</td>
<td>18” to 72”</td>
<td>0.013</td>
<td>Use at least 16 gage pipe meeting AASHTO M 196.</td>
</tr>
<tr>
<td>Spiral Rib aluminum pipe arch – Type IR</td>
<td>20” x 16” to 66” x 51”</td>
<td>0.013</td>
<td>Use at least 16 gage pipe meeting AASHTO M 196.</td>
</tr>
</tbody>
</table>

¹The range of “n” values in parentheses indicates the range of possible “n” values for a given pipe material. Variation is due to pipe size and source of published data. The recommended value for use in design is given as the "design “n” value".

²Pipes 30” to 72” with ½” corrugation are also available.

³Based on St. Anthony Falls Hydraulic Laboratory data (used by US Aluminum and Steel)

⁴Based on AISI Steel Drainage Handbook (used by Contech)
CORROSION:
The designer should obtain pH, resistivity and sulfate content data of the soil and water for pipe locations.
Equipment to determine these parameters is maintained by the SCDOT Office of Materials and Research. When
this data is not obtained, the designer shall take a conservative approach in the specifying of pipe materials.
The designer can also refer to soil maps. Maps showing the variation of soil pH by County can be found at
www.genglab.ucdavis.edu/ding/zeneca/sc_index.htm. Corrosion resistant material should be used in areas
where there is a past history of corrosive water and soil. The type of culvert pipe material specified should only
be used within the allowable environmental limits presented in Table 3 unless additional methods of protection
are provided. Sulfate concentration is also a durability concern for concrete. Table 4 illustrates the actions
required for a given sulfate concentration.

Table 3. Allowable Environments of pH and Resistivity

<table>
<thead>
<tr>
<th>Material</th>
<th>Recommended Environments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Soil1 &amp; Water pH</td>
</tr>
<tr>
<td>Reinforced Concrete Pipe</td>
<td>4 to 9</td>
</tr>
<tr>
<td>HDPE Pipe</td>
<td>1.5 to 12</td>
</tr>
<tr>
<td>Aluminum Alloy</td>
<td>4 to 9</td>
</tr>
</tbody>
</table>

1Asphalt coatings are good soil side protection and can be used to lower the pH range by 1, provided there is low ground water, the water
pH and resistivities are as outlined above and the joint is water tight (leakage from silt-tight joints can cause an artificial ground water
condition).
2A resistivity of less than 1,000 is an indication of the presence of chlorides. As chlorides can attack the reinforcing steel, the reinforcing
steel should be epoxy coated if the resistivity is less than 1,000.

Table 4. Action Required for Concrete Pipe for Given Sulfate Concentrations

<table>
<thead>
<tr>
<th>Relative Degree of Sulfate Attack</th>
<th>Sulfate Concentrations</th>
<th>Required Action</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Percent Water-Soluble Sulfate (as SO₄) in Soil Samples</td>
<td>PPM³ Sulfate (as SO₄) in Water Samples</td>
</tr>
<tr>
<td>Negligible</td>
<td>0.00-0.10</td>
<td>0-150</td>
</tr>
<tr>
<td>Positive</td>
<td>0.10-0.20</td>
<td>150-1,500</td>
</tr>
<tr>
<td>Severe</td>
<td>0.20-2.00</td>
<td>1500-10,000</td>
</tr>
<tr>
<td>Very Severe</td>
<td>2.00 or more</td>
<td>10,000 or more</td>
</tr>
</tbody>
</table>

³parts per million
ABRASION:
The designer should assess the abrasion potential for culvert pipe installations. The slope of the stream and the size of the stream bed material should be considered. The velocity of the flow in the channel upstream of the culvert pipe and in the culvert pipe should be calculated to determine if the abrasives could be transported at a sufficient velocity to cause damage to the invert of the conduit. A frequent storm velocity (Q2 velocity or five year design velocity, v) shall be used to determine abrasion potential. The designer should consider abrasion of the culvert invert as well as flow capacity and sediment transport in establishing the slope of the culvert. Where low bed loads are present (“i.e.” a closed system such as a storm sewer), higher velocities are not of concern. The necessary adjustments for various abrasion levels are shown in Table 5. Note that high velocity systems can create a number of problems including scour of outlets, manholes, catch basins and junction boxes, and require a special design.

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>ABRASION LEVEL</th>
<th>ABRASION LEVEL</th>
<th>ABRASION LEVEL</th>
<th>ABRASION LEVEL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Typical Storm Design Velocity, v)</td>
<td>(Typical Storm Design Velocity, v)</td>
<td>(Typical Storm Design Velocity, v)</td>
<td>(Typical Storm Design Velocity, v)</td>
</tr>
<tr>
<td>Reinforced Concrete Pipe</td>
<td>Low Abrasion (v = 0 to 5 fps)</td>
<td>Mild Abrasion (v = 5 to 10 fps)</td>
<td>Moderate Abrasion (v = 10 to 15 fps)</td>
<td>Severe Abrasion (v &gt; 15 fps)</td>
</tr>
<tr>
<td></td>
<td>No Addition</td>
<td>No Addition</td>
<td>No Addition</td>
<td>At least 2” concrete cover over reinforcing steel</td>
</tr>
<tr>
<td>HDPE Pipe</td>
<td>No Addition</td>
<td>No Addition</td>
<td>No Addition</td>
<td>No Addition</td>
</tr>
<tr>
<td>Aluminum Alloy</td>
<td>No Addition</td>
<td>No Addition</td>
<td>Add one gage</td>
<td>Add one gage &amp; paved invert</td>
</tr>
</tbody>
</table>

STRUCTURE:
The maximum cover and minimum cover for all pipes are found in Tables 6 through 10. The fill heights are conservative. The designer may exceed the limits set if the pipe is designed in accordance with appropriate AASHTO Design standards from the Standard Specification for Highway Bridges, American Association of State Highway and Transportation Officials, Washington D.C., 2002 or the new AASHTO LRFD Bridge Design Specifications, American Association of State Highway and Transportation Officials, Washington D.C., 2005, as stated in Table 11.

Minimum fill height for all types of pipe is measured from the top of the pipe to the top of soil backfill, excluding any prepared stone base or pavement. All pipes should meet minimum cover requirements and should not be used under roadways when these minimum cover heights cannot be achieved. In some driveway applications, it may be difficult to achieve minimum cover. In these situations, every effort should be made to achieve minimum cover and any deviations from the minimum requirements will require prior approval from
the responsible SCDOT engineer. Concrete elliptical pipe and aluminum pipe arch are good alternatives to circular pipe when additional room for cover is needed.

During construction of pipe culverts, a greater minimum fill height is required. No heavy construction equipment shall be driven over any pipe culvert until the backfill is completed to the minimum allowable cover height for construction loading listed in Tables 6 through 10 so that damage does not occur to the pipe. This minimum cover must be maintained until heavy construction equipment usage is discontinued.

<table>
<thead>
<tr>
<th>Installation Type</th>
<th>Pipe Diameter (in.)</th>
<th>Maximum Height of Fill² (ft)</th>
<th>Minimum Allowable Cover Height (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Class III</td>
<td>Class IV</td>
<td>Class V</td>
</tr>
<tr>
<td>Type I</td>
<td>12-36</td>
<td>27</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>42-66</td>
<td>26</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td>72-96</td>
<td>25</td>
<td>38</td>
</tr>
<tr>
<td>Type II</td>
<td>12-30</td>
<td>19</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>36-96</td>
<td>18</td>
<td>27</td>
</tr>
<tr>
<td>Type III</td>
<td>12-42</td>
<td>14</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>48-96</td>
<td>13</td>
<td>21</td>
</tr>
<tr>
<td>Type IV</td>
<td>12-21</td>
<td>9</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>24-96</td>
<td>9</td>
<td>15</td>
</tr>
</tbody>
</table>

Notes:
¹Installation Type is per ASTM C 1479 and AASHTO Section 27, Standard Specification for Highway Bridges, Division II: Construction, American Association of State Highway and Transportation Officials, Washington D.C., 2002
²Maximum fill heights based on American Concrete Pipe Association (ACPA) Charts
³A minimum height of cover of 9 in. is acceptable if pipe is constructed under a rigid pavement and granular backfill is used.
### Table 7. Cover Heights and Gages for Corrugated Aluminum Circular Pipe

<table>
<thead>
<tr>
<th>Corrugation</th>
<th>Area (sq ft)</th>
<th>Diameter (in.)</th>
<th>Minimum Cover (ft)</th>
<th>Maximum Allowable Cover Height (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.25 x 1/2&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 x 1&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Notes:
2. Maximum cover heights are similar to current DOT Dwg 714-2
3. Maximum cover heights based on use of a well-graded granular backfill compacted to 95% standard proctor.
4. Pipes 30" to 72" with 1/2" corrugation are also available

### Table 7b. Cover Height and Gages for Corrugated Aluminum Pipe-Arch

<table>
<thead>
<tr>
<th>Corrugation</th>
<th>Equivalent Diameter (in.)</th>
<th>Span (in.)</th>
<th>Rise (in.)</th>
<th>Maximum Allowable Cover Height (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.25 x 1/2&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 x 1&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Notes:
1. Maximum cover heights based on AASHTO LRFD Bridge Design Specification, 2004
2. Pipes 48 to 60" with 1/2" corrugation are also available
3. Maximum cover heights based on use of a well-graded granular backfill compacted to 95% standard proctor.
### Table 8. Cover Height and Gages for Ribbed Aluminum Pipe - Type IR Corrugation -3/4"X3/4"X 71/2"

<table>
<thead>
<tr>
<th>Diameter (in.)</th>
<th>Maximum Allowable Cover Height (ft)</th>
<th>Minimum Allowable Cover Height (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HS-20 Vehicle Loading</td>
<td>Construction Vehicle Loading</td>
</tr>
<tr>
<td></td>
<td>Pipe Wall Thickness (Gage)</td>
<td>Pipe Wall Thickness (Gage)</td>
</tr>
<tr>
<td></td>
<td>0.06 0.075 0.105 0.135</td>
<td>0.06 0.075 0.105 0.135</td>
</tr>
<tr>
<td></td>
<td>(16) (14) (12) (10)</td>
<td>(16) (14) (12) (10)</td>
</tr>
<tr>
<td>18</td>
<td>1 1 - -</td>
<td>3.5</td>
</tr>
<tr>
<td>24</td>
<td>1 1 1 -</td>
<td>3.5</td>
</tr>
<tr>
<td>30</td>
<td>1.25 1 1 -</td>
<td>3.5</td>
</tr>
<tr>
<td>36</td>
<td>1.5 1.25 1 1</td>
<td>3.5</td>
</tr>
<tr>
<td>42</td>
<td>- 1.5 1 2</td>
<td>3.5</td>
</tr>
<tr>
<td>48</td>
<td>- - 1.5 1.75</td>
<td>4</td>
</tr>
<tr>
<td>54</td>
<td>- - 2 2</td>
<td>4</td>
</tr>
<tr>
<td>60</td>
<td>- - - 1.75</td>
<td>4</td>
</tr>
<tr>
<td>66</td>
<td>- - - -</td>
<td>2</td>
</tr>
<tr>
<td>72</td>
<td>- - - -</td>
<td>2</td>
</tr>
</tbody>
</table>

Notes:
2. Maximum cover heights based on use of a well-graded granular backfill compacted to 95% standard proctor.

### Table 9. Cover Height and Gages for Ribbed Aluminum Pipe Arch - Type IR Corrugation -3/4"X3/4"X 71/2"

<table>
<thead>
<tr>
<th>Equivalent Diameter (in.)</th>
<th>Span (in.)</th>
<th>Rise (in.)</th>
<th>Maximum Allowable Cover Height (ft)</th>
<th>Minimum Allowable Cover Height for HS-20 Loading (ft)</th>
<th>Minimum Cover During Construction (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pipe Wall Thickness (Gage)</td>
<td>Pipe Wall Thickness (Gage)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.06 0.075 0.105 0.135</td>
<td>0.06 0.075 0.105 0.135</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(16) (14) (12) (10)</td>
<td>(16) (14) (12) (10)</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>20 16</td>
<td>17</td>
<td>1 - - -</td>
<td>1.25 - - -</td>
<td>3.5</td>
</tr>
<tr>
<td>24</td>
<td>27 21</td>
<td>12</td>
<td>- - -</td>
<td>- - - 1.75</td>
<td>4</td>
</tr>
<tr>
<td>30</td>
<td>33 26</td>
<td>11</td>
<td>- - -</td>
<td>- - - 1.75</td>
<td>4</td>
</tr>
<tr>
<td>36</td>
<td>40 31</td>
<td>10</td>
<td>- - -</td>
<td>- - - 1.75</td>
<td>3.5</td>
</tr>
<tr>
<td>42</td>
<td>46 36</td>
<td>-</td>
<td>- - 9</td>
<td>- - - 1.5</td>
<td>3.5</td>
</tr>
<tr>
<td>48</td>
<td>53 41</td>
<td>-</td>
<td>- - 8</td>
<td>- - - 1.75</td>
<td>4</td>
</tr>
<tr>
<td>54</td>
<td>60 46</td>
<td>-</td>
<td>- - 8</td>
<td>- - - 2</td>
<td>4</td>
</tr>
<tr>
<td>60</td>
<td>66 51</td>
<td>-</td>
<td>- - 9</td>
<td>- - - 1.75</td>
<td>4</td>
</tr>
</tbody>
</table>

Notes:
2. Maximum cover heights based on use of a well-graded granular backfill compacted to 95% standard proctor.
Table 10. Cover Height for Corrugated High Density Polyethylene Pipe

<table>
<thead>
<tr>
<th>Diameter (in.)</th>
<th>Maximum Allowable Cover Height (ft)</th>
<th>Minimum Allowable Cover Height (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HS-20 Vehicle Loading</td>
<td>Construction Vehicle Loading</td>
</tr>
<tr>
<td>12</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>15</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>18</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>24</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>30</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>36</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>42</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>48</td>
<td>18</td>
<td>1</td>
</tr>
<tr>
<td>54</td>
<td>18</td>
<td>2</td>
</tr>
<tr>
<td>60</td>
<td>18</td>
<td>2</td>
</tr>
</tbody>
</table>

Notes:
1. Recommend minimum Class III Backfill (ASTM D2321), compacted to 95% Standard Proctor Density
2. Maximum cover heights can be increased based on Engineer's review and approval.
REFERENCES SPECIFICATIONS
Applicable AASHTO and ASTM reference specifications are summarized in Table 11.

<table>
<thead>
<tr>
<th>MATERIAL TYPE</th>
<th>REFERENCE SPECIFICATION</th>
<th>MATERIAL TYPE</th>
<th>REFERENCE SPECIFICATION</th>
<th>INSTALLATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reinforced Concrete Pipe</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AASHTO M 170</td>
<td>AASHTO M170</td>
<td></td>
<td>AASHTO(^1)</td>
<td>AASHTO(^2,4)</td>
</tr>
<tr>
<td>ASTM C443</td>
<td>ASTM C443</td>
<td></td>
<td>Section 8&amp;16</td>
<td>Section</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>27</td>
</tr>
<tr>
<td>Elliptical Reinforced Concrete Pipe</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AASHTO M 207</td>
<td>AASHTO M 207</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>AASHTO(^1)</td>
<td>AASHTO(^2,4)</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Section 8&amp;16</td>
<td>Section</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>27</td>
</tr>
<tr>
<td>HDPE Pipe</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AASHTO M 294</td>
<td>AASHTO M 294</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>AASHTO(^1) Sect. 17</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>ASTM D3350</td>
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<td></td>
<td>AASHTO(^1)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Section 17</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrugated aluminum alloy culvert pipe</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AASHTO M 197</td>
<td>AASHTO M196</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASTM B744</td>
<td>ASTM B745</td>
<td></td>
<td></td>
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<td>AASHTO(^2,4)</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Section 12</td>
<td>Section</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>26</td>
</tr>
<tr>
<td>Aluminum Alloy Spiral Rib Pipe Type IR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AASHTO M 197</td>
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<td></td>
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<td>AASHTO(^2,4)</td>
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<td></td>
<td></td>
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<td></td>
<td>26</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^3\)Reference: AASHTO LRFD Bridge Design Specifications, American Association of State Highway and Transportation Officials, Washington D.C., 2004
\(^4\)Reference: AASHTO LRFD Bridge Construction Specifications, American Association of State Highway and Transportation Officials, Washington D.C., 2004

2-11
JOINTS:
Joint requirements are summarized in Table 12. Minimum joint performance is “soil tight” for all storm drains, cross drains and side drains. “Soil tight” joints must be watertight to 2 psi. Pipe joints shall be sealed in a manner appropriate to the pipe material. Comply with manufacturer’s recommendations for connecting pipes to concrete headwalls, catch basins, and similar structures.

When installing pipe in fine sands, the tightest joint possible should be used. Joints should be wrapped with a geosynthetic fabric to prevent fine sands from running through joints into the pipe.

<table>
<thead>
<tr>
<th>TYPE OF PIPE</th>
<th>JOINTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reinforced concrete culvert pipe</td>
<td>Joints shall meet SCDOT Standard Specifications for Highway Construction, Section 714.12 and be either the mortar mix type joint or a resilient type material gasket conforming to M 198.</td>
</tr>
<tr>
<td>High Density Polyethylene culvert pipe (HDPE)</td>
<td>Joints shall be integral bell and spigot with rubber or neoprene gaskets conforming to ASTM F477.</td>
</tr>
<tr>
<td>Corrugated aluminum alloy culvert pipe</td>
<td>Joints shall be fully indexing locking coupling bands with rubber gaskets conforming to AASHTO M 36 and AASHTO M-196</td>
</tr>
<tr>
<td></td>
<td>The ends of helically corrugated pipe may be rerolled to form at least two full annular corrugations per end. The connecting band must completely index the first full corrugation.</td>
</tr>
</tbody>
</table>

Note: The AASHTO Subcommittee on Materials is currently evaluating various joint requirements. The SCDOT should consider their recommendations when they are made.

LIFE CYCLE COSTS
The final step is to analyze life cycle costs. The analysis should include the cost of initial construction and future costs for maintenance, repair, rehabilitation and replacement over the project service life. Guidance for life cycle cost analysis is found in ASTM C1131, ASTM F1675 and ASTM A930 for reinforced concrete, high density polyethylene, and aluminum alloy pipe, respectively. The US Army Corp of Engineers’ (1998) document entitled “Engineering Design: Conduits, Culverts and Pipes” provides additional guidance. To facilitate life cycle cost analysis, the methodology in ASTM C1131 has been incorporated into software entitled “Pipe Pac-2000” by the American Concrete Pipe Association (ACPA).
3.0 GUIDANCE FOR INSTALLATION OF CULVERT Pipe ON SCDOT PROJECTS

The primary AASHTO resources for design and installation of culvert pipe include AASHTO’s Standard Specification for Highway Bridges, Division I: Design and Division II: Construction (2002) and the LRFD Bridge Design Specifications (2004). Text books on the subject include: “Buried Pipe Design” (Moser, 2001), and “Structural Mechanics of Buried Pipes” (Watkins and Anderson, 2000). In addition, a general overview of design and installation of buried pipe can be obtained through a video and accompanying resource book entitled “Design and Installation of Buried Pipes” (McGrath and Howard, 1998) published by ASCE.

The recommendations presented in this section were formulated from the above resources, AASHTO and ASTM specifications, and a review of construction specifications used by transportation departments in Florida, North Carolina, Missouri, Ohio, Utah, New York, West Virginia, Virginia, Maryland and others. The SCDOT should review the recommendations below and modify Section 714 of the current SCDOT Standard Specifications for Highway Construction and other documents as deemed necessary. Some example recommended changes to Section 714 are provided in Section 7.2.

Note that the recommendations in this section primarily apply to SCDOT applications that require at least a 75 year service life (freeways) or other conduits under roadways having a 50 year service life (rural highways, suburban and urban streets, local roads and streets) as outlined in the “SCDOT Culvert Pipe Selection Guide” developed in this project. Storm sewers outside of pavements (50 year service life) or applications that require a 25 year service life (side drains, driveways and conduits outside of pavements) may require less stringent specifications in some cases.

Section 3.0 contains discussion and recommendations that are applicable to all pipe material types. Specific recommendations for HDPE, reinforced concrete and aluminum alloy pipe are presented in Sections 3.1, 3.2 and 3.3, respectively.

3.0.1 Materials

Allowable pipe materials include reinforced concrete, high density polyethylene and aluminum alloy. Circular reinforced concrete pipe (conforming to AASHTO M 170), high density polyethylene pipe-Type S (AASHTO M 294) and corrugated aluminum alloy pipe and spiral rib aluminum pipe-Type IR (AASHTO M 196) are allowed for use on all project types as shown in Table 1 of the “SCDOT Culvert Pipe Selection Guide.” Galvanized corrugated steel pipe and high density polyethylene pipe-Type C are only allowed for temporary applications.

3.0.2 Material Management

Handling. Culvert pipe must be handled and stored in such a way that no damage occurs to the pipe. Pipes, fittings and other components must be lifted and moved safely with the aid of appropriate unloading and handling equipment. Room must be sufficient to allow for handling equipment to get around the piping components.
**Inspection.** The pipe should be inspected at the time of delivery to verify that the correct products and the expected quantities are received, and that they arrived in good condition and ready for installation. Pipe walls and corrugations, gaskets, pipe ends, couplers or other joints, and accessories should be visually inspected for damage that may have occurred during shipment. Pipe should be checked to ensure it has the correct markings to indicate that it meets specification. Any damage, missing packages, incorrect product, etc., should be noted on the bill of lading at the time of shipment, and reported to the product supplier immediately.

**Storage.** The unloading site must be relatively flat and level, free of debris, and out of the way of construction traffic. The base row must be blocked to prevent sideways movement or shifting.

### 3.0.3 Installation

Those persons installing pipe must be familiar with the general zones of the pipe soil envelope (foundation, bedding, haunch area, embedment and backfill) as shown in Figure 3.1 and the appropriate materials and levels of compaction required for each as specified in ASTM and AASHTO standards (see Table 11 in the “SCDOT Culvert Pipe Selection Guide”). Note that the specific trench terminology used in each AASHTO and ASTM standard for each pipe type varies slightly. Proper installation will improve the performance of all pipe used on SCDOT projects and will assure that the service life expected is obtained. A qualified engineer should be engaged to design a proper foundation, adequate bedding and backfill.

![Figure 3.1 Standard Trench Terminology (after McGrath and Howard, 1998)](image-url)
In general, the construction sequence should be as follows:

1. Place bedding material to grade, compact.
2. Carefully shape the trench bottom to fit the bottom of the pipe for a depth of at least 10\% of its overall height.
3. Install pipe to line and grade.
4. Place and compact the haunch area of the pipe.
5. Place and compact soil in lifts up to the spring line of the pipe.
6. Complete backfilling. Backfill should be compacted in lifts to the required density.

If native soil on trench bottom is suitable for bedding, the construction sequence should be as follows:

1. Carefully shape the trench bottom to fit the bottom of the pipe for a depth of at least 10\% of its overall height.
2. Install pipe to grade.
3. Place and compact the haunch area of the pipe.
4. Place and compact soil in lifts up to the spring line of the pipe.
5. Complete backfilling. Backfill should be compacted in lifts to the required density.

In both cases, bedding shall have recesses shaped to fit any projected hubs or bells.

### 3.0.3.1 Backfill Materials

Soils are commonly classified using the Unified Soil Classification System (ASTM D 2487) or the AASHTO Soil Classification System (AASHTO M 145). In addition, ASTM D2321 divides the soils into different “Classes.” The equivalent ASTM and AASHTO Soil Classifications are shown in Table 3.1.

<table>
<thead>
<tr>
<th>Basic Soil Type</th>
<th>ASTM D 2487</th>
<th>AASHTO M 145</th>
<th>ASTM D 2321</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sn (Gravelly sand)</td>
<td>SW, SP, GW, GP Sands and gravels with 12% or less fines</td>
<td>A-1, A-3</td>
<td>Class IB: Manufactured, processed aggregates; dense graded, clean</td>
</tr>
<tr>
<td>Si (Sandy silt)</td>
<td>GM, SM, ML Also GC and SC with less than 20% passing a No. 200 sieve</td>
<td>A-2-4, A-2-5, A-4</td>
<td>Class III: Coarse-grained soils with fines</td>
</tr>
<tr>
<td>Cl (Silty clay)</td>
<td>CL, MH, GC, SC Also GC and SC with more than 20% passing a No. 200 sieve</td>
<td>A-2-6, A-2-7, A-5, A-6</td>
<td>Class IVA: Fine-grained soils with no to low plasticity</td>
</tr>
</tbody>
</table>
Use of sands and gravels for the structural backfill (bedding, haunch and embedment) will provide the greatest assurance of good performance. Sands and gravels without fines achieve good densities when dumped and excellent densities when compacted. If placed, spread and compacted in moderate lift thicknesses, excellent pipe support is assured for all typical installations. The materials provide excellent pipe performance when placed and compacted and are less sensitive to poor construction practices than other materials.

The preferred structural backfill is a well-graded sand or gravel meeting the requirements of GW or SW material (ASTM D 2487) or A-1 or A-3 (AASHTO M 145) or Classes IB and II (ASTM D 2321). Note that pea gravel is excluded from allowable gravels. Uniformly graded coarse-grained soils (GP and SP per ASTM D2487 and A-3 per AASHTO) also provide good service but are not recommended unless provisions are made to evaluate and control possible migration of fines into open voids. Coarse-grained soils with fines (GC, GM, SC, SM (ASTM D 2487) or A-2-4 or A-2-5 (AASHTO M 145) or Class III (ASTM D 2321)) or fine grained soils with at least 50% coarse grained material (sandy silts and sandy clays) provide good performance when properly placed and compacted, but are more susceptible to problems if good construction practices are not executed; therefore when using these materials, increased inspection during construction is recommended. Low plasticity silts and clays meeting the requirements of ML or CL material (ASTM D 2487) or A-2, A-4, A-5, or A-6 (AASHTO M 145) or Class IVA (ASTM D 2321) should not be used because they are difficult to properly compact in the field. If these soils are used, compaction must be closely monitored to ensure that the soil is at or near the optimum moisture content (within ±2%) and the appropriate compactive effort is used. Organics, peats, and highly plastic clays and silts (CH, MH or Class IVB) are not acceptable.

Therefore, it is recommended for SCDOT applications that require at least a 75 year service life (“freeways” as defined by the SCDOT Highway Design Manual (2003)) shall use a well-graded sand or gravel meeting the requirements of GW or SW material (ASTM D 2487) or A-1 (AASHTO M 145)) for the bedding and backfill. Uniformly graded coarse-grained soils (GP, SP and A-3) can be used if provisions are made to evaluate and control possible migration of fines into open voids.

Conduits under roadways having a 50 year service life (“rural highways”, “suburban and urban streets,” “local roads and streets” as defined by the SCDOT Highway Design Manual (2003)) shall use coarse grained soils with fines or fine grained soils with at least 50% coarse grained material and low to no plasticity (GC, GM, SC, SM, A-2-4 and A-2-5) if compaction requirements are strictly enforced. Backfill shall be compacted to at least 95% of maximum standard Proctor density per AASHTO T 99.

Storm sewers outside of pavements (50 year service life) or applications that require a 25 year service life (side drains, driveways and conduits outside of pavements) may use any of the materials above as well as fine grained soils with low to medium plasticity (CL, ML, GC, SC or A-2-6, A-2-7, A5, A6) compacted to at least 95% of maximum standard Proctor density per AASHTO T 99.

Whenever possible, native soils should be used as backfill materials to minimize cost. Native soils in South Carolina range from sands and gravelly sand in the Coastal Plain Region to low plasticity clays in the Piedmont and Blue Ridge Regions. Native soils classified as low plasticity silts and clays meeting the requirements of ML or CL material (ASTM D 2487) or A-2, A-4, A-5, or A-6 (AASHTO M 145) or Class IVA
(ASTM D 2321) can be blended with select materials to make a suitable backfill material. When compacting native fine grained soils, the moisture content and compactive effort must be closely monitored to ensure adequate compaction. In areas where appropriate backfill and bedding materials are not available, select materials must be specified and used.

Material used for bedding and backfill shall not contain rocks, frozen lumps, chunks of highly plastic clay, organic material such as tree roots, or other deleterious material. These materials can cause point loads on the pipe or decompose to create voids.

One alternative to specifying coarse-grained backfill materials is to specify a flowable fill. Controlled low strength material (CLSM) and controlled density fill (CDF) are flowable fills which may be used for bedding and backfill. The mixture design should be specified so that the material is excavatable after it reaches full strength. Restraint must be provided to prevent flotation of any pipe type.

### 3.0.3.2 Trenching

The trench shall be excavated on line and after excavating the trench the bedding shall be placed to the proper thickness to establish the grade. Proper alignment is established by field survey. The top of the bedding should be adjusted to allow for the difference between the plan invert (flowline) and pipe profile wall thickness.

The sidewalls of a trench must remain stable throughout construction. Trenches should be left open for the least possible time because they may destabilize, flood, freeze or become a safety hazard. In some cases a moveable trench box may be needed to provide a safe working area by preventing the side walls from caving in. The trench box must be moved with care to avoid damaging the pipe or disturbing the compacted soil. Comply with all Occupation Safety and Health regulations when excavating and trenching. Note that there are safety restrictions for trenches deeper than 4 feet. Workers in the trench must stay within the trench box when utilized.

Trench dimensions depend on site conditions, the soil encountered, the type of pipe and its size and shape. The trench width must be wide enough to allow joining pipe and proper placement and compaction of the backfill. For rigid pipe, the trench should only be as wide as necessary to properly compact the backfill around the pipe. For flexible pipe, the side support comes from the combined stiffness of the trench wall and the embedment soil. Therefore, if the trench wall soil is stronger than the embedment soil, minimum space is needed. If trench walls are soft and weak, a greater width of compacted embedment or stronger embedment soil is needed. As a guide, the AASHTO LRFD Bridge Design Specifications (2004), Section 12, recommends that the minimum trench width should not be less than the greater of the pipe diameter plus 18 in. or the pipe diameter times 1.5 plus 12 in.

The trench foundation provides the base for the bedding material and must provide uniform, stable support for the pipe. Soils for the foundation may consist of the native soil or a modification. Organic material or soft or low density soil is not suitable because it can cause differential settlement. Very soft, wet soils should be replaced or reinforced by working in drier or stronger soil and compacting well. Geotextiles and geogrids can be used to reinforce unstable soils or to separate bedding and backfill from native soils.
3.0.3.3 Bedding

Bedding is the prepared material placed on the bottom of the trench on which the pipe is placed. It must be level and uniform. The function of the bedding is to support the pipe, distribute the load on the bottom and maintain the specified grade for gravity lines. The thickness of the bedding depends on pipe type and diameter. It is imperative that the pipe be cradled to provide proper support. Cradling can be accomplished in two ways: 1) Bedding under the pipe for the central one-third of the pipe outer diameter shall be placed loosely and left uncompacted for a depth of 10% of the pipe outer diameter (e.g. 2.4 in. depth for a 24 in. diameter pipe). This will provide a softer cushion to support the pipe and will mitigate the effects of poor haunching; or 2) As stated in Section 714.10 of the SCDOT Standard Specifications for Highway Construction, “the trench bottom shall be carefully shaped to fit the bottom of the pipe for a depth of a least 10% of its overall height and shall have recesses shaped to fit any projected hubs or bells.”

Proper preparation of the bedding soils is important to avoid separation of joints and misalignment of pipes. Because uniformly graded sands and gravels can serve as a drain and contribute to the migration of fines, such soils should only be used if provisions are made to prevent the migration of fines.

The finished bed for the pipe should be free of rock formations, protruding stones, frozen lumps, roots, organics and other foreign matter that may cause unequal settlement or point loads on the pipe.

3.0.3.4 Laying Pipe

Prior to laying the pipe, pipes shall be checked for damage and cleaned of debris. Pipe shall be carefully laid as shown on the plans or as approved by the responsible engineer. Throwing or rolling pipes into the trench can damage the pipe and disturb the bedding. Pipe shall be laid starting at the down stream end. The bell or socket end of the pipe should face upstream. The bottom of the pipe shall be in contact with the bedding throughout its length. As the work progresses, the interior of all pipes shall be carefully inspected and all soil, trash, rags, and other foreign matter removed from the interior.

3.0.3.5 Joints

Joint requirements are summarized in Table 12 of the “SCDOT Culvert Pipe Selection Guide” in Section 2. Minimum joint performance is “soil tight” for all storm drains, cross drains and side drains. “Soil tight” joints must be watertight to 2 psi. Pipe joints shall be sealed in a manner appropriate to the pipe material. Manufacturer’s recommendations should be used for connecting pipes to concrete headwalls, catch basins, and similar structures.

When installing pipe in fine sands, the tightest joint possible should be used. Joints should be wrapped with a geosynthetic fabric to prevent fine sands from running through joints into the pipe.

The SCDOT should consider installing a filter fabric jacket around all pipe joints and the joint between the pipe and the structure as is currently required by the Florida DOT. The FLDOT specification is as follows: The fabric shall extend a minimum of 12 inches beyond each side of the joint or both edges of the coupling band, if a coupling band is used. The fabric shall have a minimum width of 24 inches and a length sufficient to
provide a minimum overlap of 24 inches. Secure the filter fabric jacket against the outside of the pipe by metal or plastic strapping or by other methods approved by the Engineer.

It is important to note that the AASHTO Subcommittee on Materials is currently evaluating various joint requirements. The SCDOT should consider their recommendations when they are made.

### 3.0.3.6 End Treatment

End treatments at both the outlet and inlet ends should be constructed immediately after the pipe is placed. Protection of pipes ends is required for all pipes to ensure safety and facilitate maintenance around the pipe end. End treatments should be placed at each cross drain, side drain, or storm sewer pipe end. End treatments can either be constructed of riprap or consist of beveled ends with concrete pads.

### 3.0.3.7 Backfilling

It is important to select appropriate material for the backfill envelope (pipe embedment zone) and compact it properly to ensure adequate pipe support. Placing and compacting the embedment soil in accordance with specifications is the most important stage of installation. The embedment zone can be divided into three general zones: bedding, haunching, and initial backfill (structural backfill). The final backfill (cover) is placed above the initial backfill.

The haunching area is the portion of the embedment under the pipe from the bottom of the pipe to the spring line which must be placed with care and compacted well. Adequate compaction is critical in the haunching zone to properly support the pipe. The height of the first lift must be sufficiently below the spring line such that material can be worked into the haunch zone of the pipe. The backfill shall be placed and compacted with care under the haunches of the pipe and shall be brought up evenly on both sides of the pipe by working backfill operations from side to side.

The embedment soil should be spread equally on both sides of the pipe and compacted to be dense and stable. Lift thickness must be controlled, especially on larger diameter pipe. For clean, coarse grained soils the lift placement depth should be 12 in. For coarse-grained soils with fines, the lift placement depth should be 9 in. and result in a compacted lift thickness of 6 in. Trenches must be free of water when placing and compacting backfill.

The current SCDOT specified level of compaction to 95% standard proctor density exceeds current AASHTO specifications. This specification is appropriate, however the SCDOT must be guaranteed that this compaction level has been met in the field for applications that require at least a 75 year service life (freeways) or other conduits under roadways having a 50 year service life. It is recommended that the SCDOT inspectors perform density checks on compacted backfill using a geogage or nuclear density gage to verify that adequate compaction has been achieved. In addition, contractors should furnish similar quality control data to the SCDOT. Density checks should be made at the springline of the pipe to ensure that compaction is adequate in the haunches, where it is most critical. Both the geogage and the nuclear density gage are reliable and
economical methods for verifying compaction levels in the field. Note that using the nuclear gage in trenches requires a trench correction factor.

Current SCDOT specifications allow rolling or operating heavy equipment longitudinally parallel with the culvert to supplement backfill compaction, provided care is taken to avoid displacement or damage of the pipe. This procedure is not acceptable for flexible pipes such as HDPE and aluminum pipe and is questionable for concrete pipes because it can cause separation of joints and misalignment of pipes. It is recommended that this procedure be discontinued and not allowed for any type of pipe. Heavy construction equipment shall be driven over a pipe culvert only when minimum cover heights for construction vehicle loading have been achieved (see Tables 6 through 10 of the “SCDOT Pipe Selection Guide” in Section 2).

3.0.3.8 Cover Heights

The SCDOT specifications must include minimum and maximum cover heights above the pipe. Cover height tables have been developed for the SCDOT and are presented in the “SCDOT Culvert Pipe Selection Guide.” The cover height tables were developed based on AASHTO Specifications and a review of the cover height tables used by transportation departments in Florida, North Carolina, West Virginia, Missouri and others.

Minimum fill height for all types of pipe is measured from the top of the pipe to the top of soil backfill. All pipes should meet minimum cover requirements and should not be used under roadways when these minimum cover heights cannot be achieved. In some driveway applications, it may be difficult to achieve minimum cover. Concrete elliptical pipe and aluminum pipe arch are good alternatives to circular pipe when additional room for cover is needed.

Minimum fill heights in the “SCDOT Culvert Pipe Selection Guide” are in agreement with Section 12 of the AASHTO LRFD Bridge Design Specifications (2004) with one exception: reinforced concrete pipe installed with compacted granular fill under a rigid pavement can have a minimum cover of 9.0 in.

A greater minimum fill height is required above pipe culverts to prevent damage to the pipe from loads induced by heavy construction equipment. Therefore, no heavy equipment shall be driven over any pipe culvert until the backfill is completed to the minimum allowable cover height for construction loading as presented in the “SCDOT Culvert Pipe Selection Guide” so that damage does not occur to the pipe. This minimum cover must be maintained until heavy equipment usage is discontinued.

3.0.4 Installation Inspection (QC/QA)

Inspection is essential during the entire installation process to assure the quality of the pipe-soil system. Inspection is required before, during and after construction. Before construction begins the delivered materials must be checked to see that the correct products and expected quantities have been delivered. A Certificate of Compliance should be supplied from the manufacturer. Pipe size and class must be checked against the laying diagrams or engineering drawings. Pipe should be inspected for any damage incurred during transportation.
During construction, the trench width, bedding, backfill, soil type/soil density, and fill height must be checked to ensure that they meet the specifications to ensure a proper installation. The pipe and joints must be laid according to the engineering drawings and specifications. The pipe and joints must be inspected to ensure that they are gasketed and soil tight. The bedding and backfill materials must be inspected to ensure that they meet specification and that sufficient quantities are available to backfill the pipe. Compaction and density tests must be performed at every stage of construction to ensure that the soil is compacted to the appropriate level. In addition, the SCDOT shall be furnished with quality control data from the contractor to verify that compaction requirements have been met. The thicknesses of the bedding, backfill and cover layers must be measured and checked against specifications.

Inspection of the completed pipe installation is imperative. Post-construction inspections should evaluate line and grade, joint conditions and evidence of impingement due to rocks or other debris in the backfill close to the pipe. The inspector shall verify that bedding, backfill and compaction requirements are followed during installation. Inspection of the joint conditions is important because joint separation may allow exfiltration or infiltration resulting in erosion of the soil backfill material. This can cause a reduction in lateral support and/or subsidence above the pipe, and lead to damage to roadways and other structures.

Cracking may occur in most culvert materials and can indicate overloading resulting in small (localized) failures in shear, flexure, or simple damage during installation.

The AASHTO LRFD Bridge Construction Specification (2004) requires that all pipe types be visually inspected per Section 26 (metal), Section 27 (RCP) and Section 30 (thermoplastics). Therefore, it is highly recommended that all pipes be visually inspected by walking the length of the pipe (for large pipe diameters) or using video camera equipment (for smaller diameter pipes) with laser deflection measuring devices. The laser deflectometer allows the deflection to be measured over the 360 degree pipe circumference along the entire pipe run and can be used for all types of pipe. In this way, the joints of all pipe materials can be closely inspected and the pipe alignment can be verified. For quality assurance on construction projects, the SCDOT Office of Materials and Research should perform random visual inspections of the joints and ensure alignment with laser deflection measuring devices. On maintenance projects, the SCDOT Office of Materials and Research should verify that the installed pipe meets the joint and alignment criteria.

The shape of the barrel for flexible pipe shall be inspected for evidence of flattening, buckling, bulging and out-of-roundness. This is not necessary for rigid pipe because rigid pipe will crack or fracture before appreciably deflecting. Deflections in flexible pipe shall be measured with a go/no-go mandrel or a laser deflectometer. For construction projects, the contractor should be the one to verify that the installed pipe meets the minimum deflection criteria by performing the mandrel test or using a laser deflectometer. This is consistent with the current Georgia DOT procedure. For quality assurance, the SCDOT Office of Materials and Research should perform random deflection tests on construction projects. On maintenance projects, the SCDOT Office of Materials and Research should verify that the installed pipe meets the minimum deflection criteria.

After the roadway has been completed and before final inspection of the project, the engineer should inspect all pipe locations for proper installation. Any one of the following constitutes poor workmanship and is
a cause for rejection: irregular or distorted shape; dents or bends; improper fitting joints; cracked pipe; broken bells and spigots; damaged, broken delaminated or scaled coating; loose bolts or nuts; and any damage which compromises the functionality and design life of the pipe. If a section of pipe is found to be improperly installed, the contractor should replace or repair the pipe at the contractor’s expense to the satisfaction of the engineer. Repaired or replaced pipe should be re-inspected by the engineer. For large projects, it is recommended to conduct a partial inspection after completion of a small portion of the project; this inspection can be used to adjust construction practices if necessary, and will prevent the large-scale problem of discovering a systematic flaw at the end of a project.

Installations involving minimum cover heights should be inspected to ensure that the minimum cover level is provided. In addition, the pipes should be inspected prior to and immediately after vehicular load is applied. Discernable movement in the pipe/soil structure indicates instability. In this case, the backfill should be removed and inspected to determine if it meets the backfill material requirements. If the soil is suitable, it should then be re-compacted to the proper density, especially in the haunch zone of the pipe. If the soil is unacceptable, it should be replaced before re-compaction.

By implementing good quality control/quality assurance practices, the SCDOT will assure the quality of the pipe-soil system. It should be recognized that good pipe design and good pipe installation depend on each other. SCDOT engineers should design a system that can be built in the field and those who install the pipe (contractors or SCDOT maintenance personnel) should appreciate that the pipe-soil system was designed and strive to create that system. Pipelines must be properly designed, constructed and installed to ensure long-lasting performance and meet the expected service life.

The Ohio DOT has developed a “Culvert Management Manual” which can be used as a model for the SCDOT if desired. In the manual, Ohio DOT prescribes a well-defined rating system for evaluating the condition of concrete, aluminum alloy and high density polyethylene pipe culverts. They use a scale from 0 (failed) to 9 (excellent) to rate the condition of each pipe. Inspectors first conduct an inventory inspection after installation when the culvert first becomes part of the culvert inventory. Then they perform routine inspections every 5 years. If damage or deterioration is of concern for a given culvert pipe, interim inspections will be conducted to closely monitor the pipe.

3.0.5 Maintenance

Lack of maintenance is a prime cause of improper functioning in culvert pipes. Regular periodic inspections allow the condition of the pipes to be monitored and minor damages to be repaired before they become serious.

Routine maintenance of culverts must involve cleaning and removal of obstructions, debris or sediment that block the waterway especially after heavy rainfalls. Culverts with inadequate ventilation, such as those with one end blocked by debris, or long runs of culvert pipe in urban drainage systems, may develop a lack of oxygen or hazardous concentrations of organic matter.
In South Carolina, pipe that is filled with debris and sediment is a significant problem (71% of the HDPE pipes investigated in the Phase I study were filled with sediment (Gassman et al., 1999)), especially in sideline or driveway applications. This occurs because pipes are often laid on flat grades and erosion control is not provided in the drainage ditches. This is a serious problem because heavily sedimented pipes are not providing acceptable flow for drainage.

### 3.1 INSTALLATION OF HDPE PIPE

The applicable AASHTO specifications for HDPE pipe include AASHTO Standard Specification M 294, Section 12 of the AASHTO LRFD Bridge Design Specifications, Section 18 of the Standard Specifications for Highway Bridges, and Section 30 of the Construction Section of both the Standard Specifications for Highway Bridges and the LRFD Bridge Design Specifications. ASTM also provides a number of standard specifications for HDPE pipe, the most significant of which is ASTM D 2321 which outlines the standard practice for installation of HDPE pipe. AASHTO Section 30 and ASTM D 2321 recommend proper techniques for trench excavation, placement, bedding and backfill to assure the pipe performs well during its service life. ASTM D 2321 is broadly focused on the general class of gravity flow pipelines; whereas, AASHTO Section 30 is narrowly focused on gravity flow drainage pipelines under pavements subjected to heavy wheel loads. Shallow burial is an important consideration in AASHTO Section 30.

Another useful document is the “Design Manual for High Density Corrugated Polyethylene Pipe” that was published in 2003 by the Plastic Pipe Institute (PPI). This is a comprehensive document covering all aspects of the proper use and installation of HDPE pipe, including information on the history and physical chemistry of HDPE as well as the fundamentals of hydraulic design.

These documents should serve as references for all SCDOT personnel involved with the design and installation of HDPE pipe. They have been recently updated to improve standard design and installation practices as well as material requirements for HDPE pipe. These recent changes warrant updating the guidance for installation of HDPE pipes found in Section 714 of the current SCDOT Standard Specifications for Highway Construction. The main changes required to Section 714 involve materials, installation, handling and storage, and installation deflection. A summary of these changes is provided in Section 7.2.

### 3.1.1 Materials

Allowable pipe diameter should be in accordance with AASHTO M 294, thus the SCDOT specification should limit the allowable pipes diameters to range from 12 to 60 in. (300 to 1500 mm), not “12 in. and greater.” AASHTO M 294 also includes Type D pipe. Type D indicates pipe with a smooth inner wall braced circumferentially or spirally to a smooth outer wall. It is also known as “honeycomb” pipe. SCDOT may consider this type of pipe for permanent applications, however it is not currently being readily manufactured.
3.1.1.1 Product Markings

For quality control/quality assurance, the specifications should require that all HDPE pipe be certified by the PPI or AASHTO NTPEP third party certification programs. Accordingly, the shipped pipe shall be plainly marked with the manufacturer’s name, trademark, nominal size, specification designation “AASHTO M 294”, plant designation code, and the date of manufacture or an appropriate code. If PPI is required, the pipe shall be marked with the certification stamp from PPI. The shipped fittings do not require all this information: they shall be plainly marked with the manufacturer’s identification symbol and specification designation “AASHTO M 294”.

3.1.2 Material Management

Handling and storage guidelines for HDPE pipe should be included in the SCDOT specifications. The recommended addition to the specification is based on guidance provided by CPPA, PPI and several manufacturers.

Handling. In general, HDPE pipe must be handled and stored in such a way that no damage occurs to the pipe. Pipe may be delivered either palletized or loose, depending on the type and quantity of product. Pipes, fittings and other components must be lifted and moved safely with the aid of appropriate unloading and handling equipment. While small diameter pipe and lightweight accessories can generally be handled manually, large diameter pipe require equipment. A minimum of two lifting slings of fabric or plastic, located at third points along the length, is preferred to unload the pipe from the truck.

Inspection. The pipe should be inspected at the time of delivery to verify that the correct products and the expected quantities are received. Pipe walls and corrugations, gaskets, pipe ends, couplers or other joints, and accessories should be visually inspected for damage such as cuts, gouges, delaminations, bulges, flat areas and ovality that may have occurred during shipment.

Pipe should be checked to ensure it has the correct markings as listed in Section 3.1.1.1 to indicate that it meets specification.

Storage: The unloading site must be relatively flat and level, free of debris, and out of the way of construction traffic.

Pipes should be stockpiled to a stack height no greater than 6 ft. Blocking should be provided at approximately third points along the length to prevent rolling. The removal of any one pipe should not cause shifting or rolling of any of the remaining pipes. Proper care must be taken when stacking and storing HDPE pipes with bells attached. These pipes should be stacked such that the direction of the pipe lengths shall be alternated so that the bells are not stacked on top of each other. Up to three pipes can be laid before alternating direction. Proper stacking of pipe will ensure the shape of the pipe remains circular during temporary or long-term storage.

Any protective covering of gaskets should remain until the pipe is ready for installation.
3.1.3 Installation

Section 714 of the SCDOT Standard Specifications for Highway Construction lacks guidance for proper installation of HDPE pipe. Sections 714.10, 714.11, and 714.13 need to be updated to include the standards for trenching and bedding, laying of pipe, and backfilling as specified by Section 30 of the Construction Section of both the AASHTO Standard Specifications for Highway Bridges and the AASHTO LRFD Bridge Design Specifications and Section 12 of the AASHTO LRFD Bridge Design Specifications. In addition, ASTM D 2321 provides additional guidance for installation.

**Backfill Materials:** Guidance for backfill materials is provided in ASTM D 2321 and AASHTO Section 30 of the AASHTO Standard (and LRFD) Specifications for Highway Bridges. To meet the service life requirements outlined in Section 2, the backfill requirements should follow those recommended in Section 3.0.3.1. When controlled low strength material (CLSM) or controlled density fill (CDF) is used, the pipe cannot be perforated and all joints must have gaskets.

**Laying Pipe:** Pipe must not be dumped, dropped, pushed, or rolled into the trench. Lengths of pipe should be lowered into the trench manually or with equipment depending on pipe size and trench conditions (CPPA, 1999). Light and small diameter pipes can usually be handled and placed in the trench manually, while heavier and larger diameter pipes will require appropriate handling equipment to lift, move and lower the pipe. A minimum of two lifting slings of fabric or plastic, located at third points along the length, is preferred to lay the pipe in the trench.

Pipe laying shall proceed upgrade, starting at the lower end of the grade.

**Trenching:** Following the recommendation of McGrath (2003), a minimum trench width of 1.5 times the pipe outside diameter plus 12 in. is wide enough to allow joining pipe and proper placement and compaction of the backfill. If the native soils forming the trench wall do not stand without support (this means structural support and does not include support supplied solely for worker safety in trenches), increase the trench width to provide one half diameter width of structural backfill on either side of the pipe.

When controlled low strength material (CLSM) or controlled density fill (CDF) is used, AASHTO Section 30 permits a trench width of a minimum of the outside diameter plus 12 inches.

**Cover Height:** Cover height tables were developed for high density polyethylene pipe and are presented in Table 10 in the “SCDOT Culvert Pipe Selection Guide.” The cover heights are based on Section 30 and Section 12 of AASHTO Specifications, and a review of the cover height tables used by other transportation departments.

3.1.4 Installation Inspection

Inspection requirements for HDPE pipe are outlined in Section 30 of the AASHTO LRFD Bridge Construction Specification (2004). Inspection of the completed pipe installation, including a deflection check, is imperative. Revisions to Section 30 of the AASHTO LRFD Bridge Construction Specification (2004) in 2005 state that installed pipe deflections that exceed 5 percent of the initial inside diameter may indicate that the installation was substandard. Appropriate remediation, if any, will depend upon the severity of the deflection,
the condition of the pipe, and evaluation of the factor of safety using Section 12, “Buried Structures and Tunnel Liners,” of the AASHTO LRFD Bridge Design Specifications. Installed pipe deflections that exceed 7.5 percent of the initial inside diameter will require remediation or replacement of the pipe. It is recommended that the installed pipe deflection be verified using a laser deflectometer or a 9-fin deflection gage (go/no-go mandrel). Final installation inspection shall be conducted no sooner than 30 days following completion of installation and final fill.

In addition to deflection, post-construction inspections should evaluate line and grade, joint conditions and evidence of impingement due to rocks or other debris in the backfill close to the pipe. The shape of the barrel should be inspected for evidence of flattening, bulging, buckling, and out-of-roundness. Buckling can be described as a bend, warp or crumpling and includes the following terminology: 1) hinging – a sharp crease pointed inward or outward at the 3 and 9 o’clock positions caused by yielding of the material due to an excessive bending moment in the pipe wall; 2) dimpling – a wavy or waffling pattern that occurs in the inner wall of the pipe due to local instability; and 3) wall crushing – a wrinkled effect caused from yielding in the wall produced by excessive compressive stresses.

HDPE pipe may experience splits. A split (rip, tear, or crack) is any separation in the wall material other than at a designed joint. Wall damage such as splits, dents, bulges, and creases can be serious if they are extensive (>6 inches per OHIO DOT) and impair either the integrity of the pipe in ring compression or permit infiltration of backfill. Critical damage will usually be accompanied by excessive deflection or poorly shaped cross-section. Small, localized damage is not ordinarily critical.

The Missouri DOT considers the following to constitute improper installation and should be considered for adoption by the SCDOT:

1) If any horizontal or vertical alignment is in excess of 15 percent from plan alignment, will restrict flow or will cause excessive ponding within the pipe.
2) Any section of pipe with deflections greater than 5 percent, based upon the units of measurement used in fabricating the pipe.
3) If settlement is greater than one inch at 5 percent or more joints.
4) The pipe shows evidence of being crushed or buckled at any location
5) The pipe shows evidence of joint separation.

The following recommendations are made to guide the SCDOT in the installation inspection of HDPE pipe. They are based on changes made to the ASHTO LRFD Bridge Construction Specification in 2005. For HDPE pipe, when installed pipe deflections exceed 5 percent of the inside diameter, an evaluation shall be conducted by the Contractor and submitted to the SCDOT Engineer for review and approval considering the severity of the deflection, structural integrity, environmental conditions, and the design service life of the pipe. Pipe remediation or replacement shall be required for locations where the evaluation finds that the deflection could be problematic. For locations where the installed pipe deflections exceed 7.5 percent of the initial inside diameter remediation or replacement of the pipe shall be required.
3.2 INSTALLATION OF REINFORCED CONCRETE PIPE


The American Concrete Pipe Association (ACPA) publishes many useful documents including the following: “Concrete Pipe Installation” (1995), “Concrete Pipe Design Manual” (2000), and “Concrete Pipe Handbook” (1998). These documents should serve as references for all SCDOT personnel involved with the design and installation of concrete pipe.

3.2.1 Materials

For circular reinforced concrete pipe, the material should be at least Class III pipe meeting AASHTO M 170. Pipe diameters up to 144 inches are allowed. For elliptical reinforced concrete pipe, the material should be at least Class III pipe meeting AASHTO M 207. Sizes ranging from 14 in. x 23 in. to 68 in. x 106 in. are allowed.

3.2.1.1 Product Markings

As specified in M 170 each pipe should be clearly marked by means of indentation or waterproof paint with the following: 1. the pipe class and specification designation; 2. the date of manufacture; 3. the name or trademark of the manufacturer; and 4. identification of plant. In addition, it is recommended that the SCDOT require that all concrete pipe be certified by the ACPA Q-Cast program as part of the quality control/quality assurance program. Therefore, a “Q-Cast” stamp of certification should also be present on the pipe wall, preferably in two locations: inside and outside.

3.2.2 Material Management

Handling. Concrete pipe must be handled and stored in such a way that no damage occurs to the pipe.

Inspection. The pipe should be inspected at the time of delivery to verify that the correct products and the expected quantities are received. Pipe walls, gaskets, pipe ends and accessories should be visually inspected for damage such as broken edges, cracking, delaminations, and spalling that may have occurred during shipment. Reinforcing steel should not be exposed.

Pipe should be checked to ensure it has the correct markings as listed in Section 3.2.1.1 to indicate that it meets specification.

Storage: The unloading site must be relatively flat and level, free of debris, and out of the way of construction traffic. Pipes, fittings and other components must be lifted and moved safely with the aid of
appropriate unloading and handling equipment. On construction projects, pipe must be stored outside of the clear zone where traffic is continuing to operate.

### 3.2.3 Installation

**Laying Pipe:** Rigid pipe shall be carefully laid as shown on the plans, with hub, bell or groove ends upstream and with the spigot or tongue end entered the full length into adjacent section of pipe. Elliptical reinforced pipe shall be oriented and laid such that the top and bottom of the pipe, as marked on the pipe, are in the proper position. On maintenance projects, horizontal alignment and pipe grade must be established prior to beginning to lay the pipe.

**Bedding and Backfill:** The bedding and compaction requirements for concrete pipe as specified by ASTM C1479 are shown in Table 3.2. The backfill requirements recommended in Section 3.0.3.1 to meet the service life requirements outlined in Section 2 are similar to installation Types I and II with an increased standard of compaction to 95% Standard Proctor density.

#### Table 3.2 Bedding and Compaction Requirements for Reinforced Concrete Pipe (per ASTM C 1479)\(^1\)

<table>
<thead>
<tr>
<th>Installation Type</th>
<th>Bedding Thickness</th>
<th>Haunch and Outer Bedding</th>
<th>Lower Side Bedding or Undisturbed Earth Equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Gravelly Sand(^2)</td>
<td>Sandy Silt(^3)</td>
</tr>
<tr>
<td>1</td>
<td>(D_o/24) in. minimum; not less than 3 in. If rock foundation, use (D_o/12) minimum; not less than 6 in.</td>
<td>95</td>
<td>n/a</td>
</tr>
<tr>
<td>2</td>
<td>(D_o/24) in. minimum; not less than 3 in. If rock foundation, use (D_o/12) minimum; not less than 6 in.</td>
<td>90</td>
<td>95</td>
</tr>
<tr>
<td>3</td>
<td>(D_o/24) in. minimum; not less than 3 in. If rock foundation, use (D_o/12) minimum; not less than 6 in.</td>
<td>85</td>
<td>90</td>
</tr>
<tr>
<td>4</td>
<td>No bedding required, except if rock foundation, use (D_o/12) in. minimum; not less than 6 in.</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>

1. The backfill requirements recommended in Section 3.0.3.1 to meet the service life requirements outlined in Section 2 are similar to installation Types I and II with an increased standard of compaction to 95% Standard Proctor density.
2. SW or GW material (ASTM D 2487) or A-1 or A-3 (AASHTO M 145). Uniformly graded coarse-grained soils (GP, SP or A-3) shall only be used if provisions are made to evaluate and control possible migration of fines into open voids. Pea gravel shall not be used.
3. ML, SM or GM material (ASTM D 2487) or A-4, A-2-4 or A-2-5 (AASHTO M 145)
4. CL, GC or SC (ASTM D 2487) or A-2-6 or A-2-7, A-5, A-6 (AASHTO M 145)
Separation of joints is the most common problem with concrete pipe installations. Therefore, proper preparation of the bedding soils and sufficient compaction of the backfill soil (especially in the haunches) is important for rigid pipe.

Cover Heights: Cover height tables were developed for reinforced concrete pipe and are presented in Table 6 in the “SCDOT Culvert Pipe Selection Guide.” Elliptical concrete pipe is a good alternative to circular pipe when additional room for cover is needed.

3.2.4 Installation Inspection

Inspection requirements for reinforced concrete pipe are outlined in Section 27 of the AASHTO LRFD Bridge Construction Specification (2004). Post-construction inspection of reinforced concrete pipe should evaluate line and grade, joint conditions, cracking, spalling, delaminations and exposed reinforcing steel. The pipes should be visually inspected by walking the length of the pipe (for large pipe diameters) or using video equipment (for smaller diameter pipes) with laser deflection measuring devices.

Misalignment indicates the presence of serious problems in the supporting soil. The vertical and horizontal alignment of the pipe shall be checked for differential movement or settlement at joints between pipe sections. Vertical alignment shall be checked for sags, faulting and invert heaving. Horizontal alignment shall be checked for straightness or smooth curvature.

It is important for the inspector to verify that bedding, backfill and compaction requirements are followed during installation. This is because poor compaction and/or inadequate bedding and backfill materials will result in the separation of joints. Sometimes the joints separate immediately after construction, but joints can also separate after years of repeated vehicular loading.

Joint separations are considered to be significant because they accelerate damage caused by exfiltration and infiltration resulting in the erosion of the backfill material. Leakage at joints should be noted but is not necessarily serious unless other problems are evident, such as differential movement, large cracks or spalling, improper gasket placement, and movement or settlement of pipe sections. Severe joint cracks are similar in significance to separated joints.

The location of the cracking in concrete structures can indicate the nature of problems being experienced. Longitudinal cracks at the 3, 6, 9 and 12 o’clock positions indicate flexure cracking caused by poor side support. Longitudinal cracks at the 5 and 7 o’clock positions indicate shear cracking caused by poor haunch support and longitudinal cracks at the 11 and 1 o’clock positions may be the result of shear forces from above the pipe. Transverse cracks are usually the result of non-uniform bedding or fill material causing point loads on the pipe.

Because the reinforcing steel is designed to carry some of the imposed loads in concrete pipe, small hairline cracks (smaller than 0.01 in. in width) are expected and are considered to be minor. According to Section 27 of the AASHTO LRFD Bridge Construction Specification (2004), cracks greater than 0.01 in. but less than 0.1 in. should be considered for maintenance. Cracks greater than 0.1 in. in width may indicate overloading or poor bedding and require that the original design and installation be evaluated to see if the pipe
needs to be replaced. All cracks should be noted and monitored to see if they grow with time, indicating movement or overloading of the pipe.

The Missouri DOT considers the following to constitute improper installation and should be considered for adoption by the SCDOT:

1) If any horizontal or vertical alignment is in excess of 15 percent from plan alignment, will restrict flow or will cause excessive ponding within the pipe.
2) If settlement is greater than one inch at 5 percent or more joints.
3) The pipe shows evidence of separation at any location.

The following recommendations are made to guide the SCDOT in the installation inspection of concrete pipe. They are based on changes made to the ASHTO LRFD Bridge Construction Specification in 2005. For concrete pipe, when signs of distress, such as differential movement, efflorescence, spalling, rust stains or cracks wider than 0.01 in. are present in the pipe, an evaluation shall be conducted by the Contractor and submitted to the SCDOT Engineer for review and approval considering the structural integrity, environmental conditions, and the design service life of the pipe. Cracks having widths equal to or greater than 0.01 in. and determined to be detrimental shall be sealed by a method approved by the SCDOT Engineer. Pipes with cracks having widths greater than 0.1 in. and determined by the SCDOT Engineer to be beyond satisfactory structural repair shall be remediated or replaced. Pipes having displacement across the crack shall be repaired or replaced. Pipes experiencing spalls or delaminations shall be repaired or replaced.

3.3 INSTALLATION OF ALUMINUM ALLOY PIPE

The applicable AASHTO specifications for aluminum alloy pipe include Section 12 of the AASHTO LRFD Bridge Design Specifications (2004), Section 12 of the AASHTO Standard Specifications for Highway Bridges, Division I: Design (2002) and Section 26 of the AASHTO Standard (and LRFD) Specifications for Highway Bridges, Division II: Construction (2002, 2004). The materials for aluminum alloy pipe shall meet the requirements of AASHTO Standard Specifications M 196 and M 197. These documents should serve as references for all SCDOT personnel involved with the design and installation of aluminum pipe.

3.3.1 Materials

The material for aluminum alloy sheet shall be in accordance with AASHTO M 197 and the corrugated aluminum alloy pipe shall meet AASHTO M 196. The pipe should be at least 16 gage. Aluminum alloy culvert pipe with ½” deep corrugation is available in diameters ranging from 12 to 72 in. and aluminum alloy culvert pipe with 1” deep corrugation can range in diameter from 30 to 120 in. The SCDOT prefers to limit the diameters of aluminum alloy culvert pipe with ½” deep corrugation to 24 in. for simplicity in pipe selection by avoiding overlap in diameters with the 1” deep corrugations. Spiral rib aluminum pipe – Type IR (smooth walled) is also permitted in sizes ranging from 18 to 72 in.
The aluminum alloy sheets or coils supplied for aluminum pipe can be 3004-H34 or 3004-H32. The only difference between H34 and H32 is the temper (heat treatment). This affects the ultimate tensile strength and the tensile yield strength. The H34 has a yield strength of 24,000 psi while the H32 has a yield strength of 20,000 psi. H32 material is more malleable (can elongate more before it breaks) which makes it easier to make helical pipe because it forms better in the machinery and also rerolls better than H34. Note that ASTM B745 has recently deleted reference to the 3004-H34 material for helical pipe (but continues reference to 3004-H34 for riveted pipe) and the AASHTO Subcommittee on Materials is expected to do the same according to Contech representatives.

Different manufacturers make different systems for joining pipe. For example, US Aluminum and Steel’s 3004-H34 ALCLAD aluminum alloy culvert pipe has a “positive lock” joining system and Contech’s CORLIX pipe has an optional feature of annular rerolled ends and a HUGGER® Band. When rerolled ends are used, it is recommended to use a minimum of 2 rerolls per end and a connecting band that completely indexes the corrugation. The advantages of rerolled ends include 1) getting a stronger and tighter joint and 2) ease of installation (helical pipe doesn’t need to be rotated to align corrugations).

Currently, the SCDOT does not allow “rerolled ends” on aluminum pipe because of concerns that rerolling creates a weak zone at the pipe end. According to Contech representatives, SCDOT is the only DOT that does not allow them; therefore several state DOT’s including Georgia, North Carolina and Florida were asked about their experience with aluminum pipe with rerolled ends to see if they have had any problems with the pipe. They all reported having limited use with aluminum pipe but stated that they currently were not having any problems with it. Therefore, based on the experience of other transportation departments, rerolled ends should be considered for use on SCDOT projects. To gain experience with rerolled ends, it is recommended that the SCDOT install a side by side comparison of aluminum pipe with rerolled ends and aluminum pipe without re-rolled ends. The installation and performance should be carefully monitored.

It should be noted that the current SCDOT specification allows for spiral rib aluminum pipe – Type IR. This is Contech’s ULTRA FLO storm sewer pipe which is only made with rerolled ends, thus sections of this type of pipe cannot be connected if rerolled ends are not permitted.

### 3.3.1.1 Product Markings

As specified in M 197, each corrugated sheet furnished for use in corrugated pipe shall be identified by the sheet manufacturer showing the following: 1) name or trademark of sheet manufacturer, 2) alloy and temper, 3) specified thickness, 4) date of corrugating by a six-digit number indicating in order the year, month, and day of the month and 5) AASHTO designation number M 197. In addition, as specified in M196, the fabricated pipe shall be identified with 1) the identification of the pipe fabricator, 2) fabricator’s date of forming into pipe by a six-digit number indicating in order the year, month, and day of the month and 3) AASHTO designation number M 196. The markings shall be applied to the outside of the pipe by a permanent method such as coining (ASTM B 666). These product markings specified by AASHTO M 197 are the same as those specified by ASTM B 744-05.
3.3.2 Material Management

Handling. Aluminum pipe shall be handled to avoid damage.

Inspection. The pipe should be inspected at the time of delivery to verify that the correct products and the expected quantities are received. Pipe walls and corrugations, gaskets, pipe ends, couplers or other joints, and accessories should be visually inspected for damage such as cracking at bolt holes, localized distortions, bulging or flattening that may have occurred during shipment. Pipe having any localized bends in excess of five percent of the specified pipe diameter, or any dent in excess of 1/2 inch (13 mm) should be rejected, regardless of previous approvals. Rejected damaged pipe may be used if repaired to the satisfaction of the engineer.

Pipe should be checked to ensure it has the correct markings as listed in Section 3.3.1.1 to indicate that it meets specification.

Storage. The unloading site must be relatively flat and level, free of debris, and out of the way of construction traffic. Pipes, fittings and other components must be lifted and moved safely with the aid of appropriate unloading and handling equipment.

3.3.3 Installation

Backfill Materials: Bedding and backfill material shall be a readily compacted soil or granular fill material. Excavated native soils used as structural back fill shall not contain large particles such as rocks, frozen lumps, chunks of highly plastic clay, organic material or other deleterious material.

Bedding: For corrugated aluminum pipe, the loosely placed bedding under the central one-third of the pipe diameter shall be placed with a minimum thickness of twice the corrugation depth. Material in contact with the pipe shall not contain rocks, frozen lumps, chunks of highly plastic clay, organic material or other deleterious material.

Laying Pipe: Aluminum pipe shall be carefully laid to line and grade as shown on the plans or determined by the supervising engineer.

Cover Height: Cover height tables were developed for aluminum alloy pipe and are presented in Tables 7 to 9 in the “SCDOT Culvert Pipe Selection Guide.” Aluminum alloy pipe arch is a good alternative to circular pipe when additional room for minimum cover is needed.

Note that the height of cover tables given in the “SCDOT Culvert Pipe Selection Guide” were derived from the Standard Specifications for Highway Bridges, American Association of State Highway and Transportation Officials, Washington D.C., 2002 for corrugated aluminum circular pipe in Table 7 and from the LRFD Bridge Design Specifications, American Association of State Highway and Transportation Officials, Washington D.C., 2004 for corrugated aluminum pipe-arch in Table 7b and for ribbed aluminum pipe and pipe arch in Tables 8 and 9. Table 7 could be derived from the LRFD Bridge Design Specifications as well and would result in maximum cover heights approximately 2% greater than shown in the table, thus the maximum cover heights shown in Table 7 are conservative. This is because the LRFD procedure uses a 1.95 load factor on dead load (versus 2.0) with a live load factor of 1.7 and a multiple presence factor of 1.2 to give a combined
live load factor of 2.04. At high covers the live load is insignificant and LRFD gives about 2% more height of cover, but at lower covers it is more conservative.

Also, the heights of cover in Tables 6 to 9 were derived using 3004-H32 Coil specifications. Since height of cover depends directly on yield strength, the H32 materials can carry only 83.3% as much maximum cover (i.e. 20,000/24,000). If the pipe is made from H34 material, these tables can be used and are conservative.

Early in the course of this project, aluminum pipe representatives expressed concern that the current SCDOT height of cover tables for corrugated aluminum pipe were non-conservative for some diameters. In addition, the pipe diameter should be limited to 120 in. As of the date of this report, the SCDOT Standard Drawing 714-2 was revised by the SCDOT to correct the non-conservative cover heights and it does include revision to limit pipe diameter to 120 in. In large diameter aluminum pipe, flexibility factor failure is a concern.

3.3.4 Installation Inspection

Inspection requirements for corrugated aluminum alloy pipe and spiral rib pipe are outlined in Section 26 of the AASHTO LRFD Bridge Construction Specification (2004). Pipe shall be checked for alignment, joint separation, cracking at bolt holes, localized distortions, bulging, flattening, or straining. Racking or denting of the pipe shall be taken to indicate improper backfill placement, which shall be corrected. Wall sections damaged during installation shall be evaluated and then repaired or the section of the pipe shall be replaced.

Slight peaking of the cross-sectional shape should be taken as indicative of achieving or exceeding minimum compaction requirements. Generally, an initial change in vertical and/or horizontal dimensions, where the shape remains smooth, concentric, and constant over time should not be taken as structurally significant. However, if these dimensions do not remain constant, the affected length should be replaced.

Cracking may occur along bolt holes of longitudinal seams and can be serious if allowed to progress. These cracks are most serious when accompanied by significant deflections or distortions indicative of improperly placed bedding or backfill. Wall damage such as dents, bulges, creases, cracks and tears can be serious if they are extensive and impair either the integrity of the pipe in ring compression or permit infiltration of backfill. Critical damage will usually be accompanied by excessive deflection or poorly shaped cross-section. Small, localized damage is not ordinarily critical. Deflections in aluminum alloy pipe shall be measured with a go/no-go mandrel or a laser deflectometer.

Deep pitting, perforations throughout the invert and overall thin metal which allows for an easy puncture with a chipping hammer are of serious concern.

The Missouri DOT considers the following to constitute improper installation and should be considered for adoption by the SCDOT:

1) If any horizontal or vertical alignment is in excess of 15 percent from plan alignment, will restrict flow or will cause excessive ponding within the pipe.
2) Any section of pipe with deflections greater than 10 percent, based upon the units of measurement used in fabricating the pipe.
3) If settlement is greater than one inch at 5 percent or more joints.
4) The pipe shows evidence of being crushed at any location.
5) The pipe shows evidence of joint separation.

Personal communication with Tim McGrath (July, 2005) revealed that AASHTO has just revised the inspection requirements for metal pipe. They require a post construction inspection, but do not impose a specific deflection limit. Florida DOT now limits metal pipe deflection to 5%. The rationale for setting a 5%, 7.5% or a 10% deflection limit for metal pipe is still being studied.

The following recommendations are made to guide the SCDOT in the installation inspection of aluminum pipe. They are based on changes made to the ASHTO LRFD Bridge Construction Specification in 2005. For aluminum pipe, when pipe distress such as cracking along bolt holes, wall damage (dents, bulges, creases, cracks and tears) and excessive deflection or poorly shaped cross-section are present in the pipe, an evaluation shall be conducted by the Contractor and submitted to the SCDOT Engineer for review and approval considering the structural integrity, environmental conditions, and the design service life of the pipe. Pipe remediation or replacement shall be required for locations where the evaluation finds that the distresses could be problematic.
4.0 THIRD PARTY CERTIFICATION PROGRAMS

Third party certification is a process by which a third party validates through testing and inspection that a manufacturer’s product meets the requirements of a standard. The benefits of a third party certification include: a) establishing the credibility of an industry’s product, b) eliminating inferior products by certifying to industry standards, c) end-user can easily identify a certified product by specific markings, d) assuring consistency by same laboratory conducting tests, and e) reducing end-user costs (Palermo, 2002). According to Palermo (2002) the following are considered to be components of a successful certification program: 1) qualification – initial product testing to ensure compliance with requirements and outlines in an industry standard; 2) unannounced inspections – plants are periodically inspected. Raw materials and finished products are tested at random to confirm conformance with industry standards; and 3) program mark – the permanent label on a product that can be easily recognized by end-user and indicates product is qualified under a certain program.

Currently there are third party certification programs for HDPE pipe and concrete pipe. The third party certification programs for HDPE pipe include programs by the Plastic Pipe Institute, Inc. (PPI) and AASHTO National Transportation Product Evaluation Program (NTPEP). The programs for concrete pipe include American Concrete Pipe Association (ACPA) Quality Cast or “Q-Cast” program and the National Precast Concrete Association (NPCA) Plant Certification Program.

4.1 THIRD PARTY CERTIFICATION PROGRAMS FOR HDPE PIPE

4.1.1 Third Party Certification Program by PPI

This certification program sponsored by the Plastic Pipe Institute, Inc. (PPI), concerns corrugated polyethylene pipe manufacturers that want to certify that their products meet or exceed the requirements in AASHTO M 294/MP 7 (12 to 48 in. diameter/54 to 60 in. diameter (300 to 1200 mm diameter/1350 to 1500 mm diameter)). The document summarizing this program is entitled: “Third Party Certification Protocol” (PPI, 2004) and can be found on their web site: http://www.plasticpipe.org/applications/certprogram03_2_8.php

The Program Administrator (selected by PPI and currently TRI/Environmental in Austin, TX) is responsible for the validation of Manufacturer’s certification, through testing, inspection and review of HDPE resin and finished product. The Administrator will periodically inspect the manufacturer’s facility to determine continuing compliance with the requirements of the program and the functioning of a quality program. The Manufacturer and PPI will be notified of compliant (or non-compliant) products.

A Manufacturer (resin and pipe producers) contracts with PPI for program participation and will be listed by PPI in a directory of participating Manufacturers if the program requirements are met. The Manufacturer is also eligible to use Program Marks for the Administrator-validated product. For a Manufacturer that has more than one facility, each facility producing qualified products must participate in the program. Here is a summary of the process:

- Manufacturer (resin or pipe) applies for certification.
- Administrator tests product(s) to verify compliance.
Assuming compliance, Administrator notifies Manufacturer and PPI.
PPI publishes on its website - www.plasticpipe.org.
PPI lists Manufacturer and products in directory.
PPI licenses use of Program Mark.
Administrator makes periodic, unannounced inspections to validate certification.

The PPI program is now in effect. Certified resin and certified pipe listings are now available. All high density polyethylene resin products listed in Table 4.1 meet the requirements established by Section 6.1 in AASHTO M 294 or MP7 as applied by the PPI Third Party Certification Program. All high density polyethylene pipe products listed in Table 4.2 meet the requirements established in AASHTO M 294 or MP7 as applied by the PPI Third Party Certification Program.

It is recommended that the SCDOT use PPI’s list of certified pipes to establish their approved/qualified products list. All pipes and resins certified by PPI meet the requirements of the AASHTO Material Specifications M294.

### Table 4.1: PPI Certified Resin (January 2005)

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Resin</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADS</td>
<td>GS100</td>
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<tr>
<td>ATOFINA Petrochemicals, Inc.</td>
<td>Finathene® CD-522</td>
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<td>Chevron Phillips Chemical Company</td>
<td>Marlex® C514</td>
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<tr>
<td>Dow Chemical Company</td>
<td>DGDA 2475</td>
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<td>Exxon Mobil Chemical</td>
<td>HDA-020</td>
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<td></td>
<td>HD7800P</td>
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<td></td>
<td>Paxon AA53-003™</td>
</tr>
<tr>
<td>Equistar Chemical LP</td>
<td>Alathon L5332CP (formerly LYHD048)</td>
</tr>
<tr>
<td>Formosa Plastics Corporation</td>
<td>Resin FPC HP5221</td>
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<td>Resin FPC E602</td>
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<tr>
<td>Hancor</td>
<td>Resin 8™</td>
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<tr>
<td>NOVA Chemical Corporation</td>
<td>NOVAPOL® HP-Y353-A</td>
</tr>
<tr>
<td>BP Solvay Polyethylene North America</td>
<td>Fortiflex® CP52-35</td>
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<td>Fortiflex® K54-05</td>
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<td></td>
<td>Fortiflex® G50-100</td>
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<tr>
<td>Petromont, Inc.</td>
<td>Petromont HDPE 4101</td>
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Table 4.2: PPI Certified Pipe (January 2005)

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Trade Name</th>
<th>Pipe Size</th>
<th>Product Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced Drainage Systems, Inc.</td>
<td></td>
<td>12&quot;, 15&quot;, 18&quot;, 24&quot; I.D.</td>
<td>Corrugated Type C/CP Polyethylene Pipe</td>
</tr>
<tr>
<td>Baughman Tile Company</td>
<td></td>
<td>12&quot;, 15&quot;, 18&quot; I.D.</td>
<td>Corrugated Type C/CP Polyethylene Pipe</td>
</tr>
<tr>
<td>Baughman Tile Company</td>
<td></td>
<td>12&quot;, 15&quot;</td>
<td>Corrugated Type S Polyethylene Pipe</td>
</tr>
<tr>
<td>Hancor</td>
<td></td>
<td>12&quot;, 15&quot;, 18&quot;, 24&quot; I.D.</td>
<td>Corrugated Smooth Type SP w/ Split Coupling Polyethylene Pipe</td>
</tr>
<tr>
<td>Hancor</td>
<td></td>
<td>12&quot;, 15&quot;, 18&quot; I.D.</td>
<td>Corrugated Smooth Type SP w/ Split Coupling Polyethylene Pipe</td>
</tr>
<tr>
<td>Hancor</td>
<td></td>
<td>24&quot; and 30&quot; I.D.</td>
<td>Corrugated Smooth Type SP w/ no joints Polyethylene Pipe</td>
</tr>
<tr>
<td>Hancor</td>
<td>Sure-Lok</td>
<td>54&quot; I.D.</td>
<td>Corrugated Smooth Type SP w/ Bell &amp; Spigot Polyethylene Pipe</td>
</tr>
<tr>
<td>Haviland Drainage Products</td>
<td></td>
<td>12&quot;, 15&quot;, 18&quot;, 24&quot; I.D.</td>
<td>Corrugated Type C/CP (no joints tested) Polyethylene Pipe</td>
</tr>
</tbody>
</table>
4.1.1.1 Recommendations for Design and Installation Reference Manuals

PPI has recently released “Design Manual for High Density Corrugated Polyethylene Pipe.” This is a comprehensive document covering all aspects of the proper use and installation of HDPE pipe, including information on the history and physical chemistry of HDPE as well as the fundamentals of hydraulic design. This document was used to help develop the training course for SC DOT personnel and should serve as a reference document for all SC DOT personnel involved with the design and installation of HDPE pipe.

4.1.2 NTPEP Project Work Plan for Evaluation of HDPE Thermoplastic Pipe

The AASHTO National Transportation Product Evaluation Program (NTPEP) is a third party certification program that is scheduled to be launched in May 2002. The purpose of this program is threefold: 1) to provide complete testing of thermoplastic pipe products in accordance with AASHTO M294M / MP7; 2) to provide a listing of pipe products (by diameter and Manufacturer) that meet the requirements of AASHTO Material Specifications; and 3) provide test results to AASHTO member departments. The specifics of the plan are outlined in “Project Work Plan for Evaluation of HDPE Thermoplastic Pipe” (NTPEP, 2002).

The manufacturer’s certification is validated by the appropriate NTPEP testing, inspection, and review of its manufacturing and testing facilities. Inspections of the manufacturing plant need not be announced. Product (including resin) will be randomly selected for confirmation testing. In addition, the manufacturer will submit its QA/QC plan for review and approval by the NTPEP Coordinator. Assuming compliance with the NTPEP and the applicable AASHTO Specifications are demonstrated, the NTPEP Administrator will list the product(s) in the NTPEP listing of tested products and publish the testing results in NTPEP reports.

This plan can be used as part of a comprehensive QA/QC plan for thermoplastic pipe and the resin from which it is manufactured. This program is advantageous to the SC DOT because State DOT materials laboratories are not generally equipped to conduct all of the tests referenced in the standards, and equipping all, or most, of the labs to do so would not be cost effective. The SC DOT should use the laboratory test data obtained from the products evaluated by NTPEP to establish their approved/qualified products list.

Representatives from the Kansas DOT, Washington State DOT, Wisconsin DOT, Arizona DOT and New York DOT along with two industry representatives comprise the NTPEP Plastic Pipe Project Panel. This panel is a working group charged with developing and maintaining the Project Work Plan for testing of plastic pipe products.

Current NTPEP reports are available for review on the NTPEP web page: http://www.transportation.org/programs/ntpep/home.nsf/AllPages/Pipe_Reports. As of June 2004, reports for ADS TYPE S Pipe sizes 15, 18, 24, 30, 36, and 42 inches are available on the web site. All ADS pipes tested met the requirements of the AASHTO Material Specifications M294. As of January 2005, reports for Soleno 10, 12, 15, 18, 30 and 36 in., Hancor 12, 18, 24 and 36 in., Lane Enterprises 15 and 24 in. and Quality Culvert 12, 15, 18, 24, 30, 36, 42, and 48 in. were also available.

The SC DOT should use the NTPEP program for Quality Assurance testing. Samples of product can be randomly selected for confirmation testing by the NTPEP participating test facilities.
4.1.3 Recommendations Regarding Third Party Certification Programs for HDPE Pipe

At this time, it is recommended that the SCDOT require HDPE pipe to be certified by the PPI or NTPEP third party certification programs to qualify for inclusion on Approval Sheet 30 as approved manufacturers of HDPE pipe. When NTPEP becomes more established, this recommendation should be revisited.

4.2 THIRD PARTY CERTIFICATION PROGRAMS FOR CONCRETE PIPE

4.2.1 American Concrete Pipe Association (ACPA) “Q-Cast” Program

The American Concrete Pipe Association (ACPA) offers an on-going quality assurance program to member and non-member companies called Quality Cast or “Q-Cast” Plant Certification Program. The program was created to improve the overall quality of all concrete pipe products. The program involves a 124-point audit-inspection program that covers the inspection of materials, finished products and handling/storage procedures, as well as performance testing and quality control documentation. Q-Cast is available for the certification of many different products, including storm sewer pipe and manholes, sanitary sewer pipe and manholes and box culverts. Plants can become certified in any of the three certifications or any combination of all three. Pipe certifications include round, arch and elliptical pipe and for gasketed and non-gasketed pipe. Details of the program are outlined in “ACPA Q-Cast Plant Certification” Version 2.0, 2004. A copy can be downloaded from ACPA’s website: http://www.concrete-pipe.org/qcast.htm. Matt Childs is the ACPA contact for the program. He can be reached at 1-972-506-7216.

To become Q-Cast certified, a plant sends an application to ACPA with a $300 application fee that will be applied to the annual cost of the inspection. ACPA will notify Wiss, Janney, Elstner Associates, Inc. (WJE), an independent engineering firm, to do the first inspection. WJE will contact the plant and schedule the first visit. Subsequent annual inspections will be made unannounced. During each inspection, the inspector reviews the plants documentation, looks at the plant and tests some of the product to make sure that it conforms to specification. In order to receive certification, plants must meet all the requirements of the ACPA’s Plant Certification Manual as determined during WJE’s audit. Upon receiving a passing score, the plant is sent a certificate authenticating certification by the ACPA. Pipe certifications include round, arch and elliptical pipe and for gasketed and non-gasketed pipe. The cost of the program is paid by each plant: $2900 per year for storm sewer pipe and manholes and $3500 per year for storm sewer pipe, manholes and box culverts. If the plant is not a member of ACPA, an additional charge of $4000 per year will apply.

The following state departments of transportation currently require concrete pipe used on their projects to be ACPA Q-Cast certified: Alabama, Colorado, Missouri, New York, Tennessee, Pennsylvania, Utah, and Wyoming. Indiana and Kansas are currently looking at requiring Q-cast as well.

If SCDOT desires, ACPA can provide each plant with a Q-Cast stencil to clearly mark each pipe. ACPA recommends that the SCDOT require each plant to stamp the pipe in two places: inside and outside.
4.2.2 National Pre-cast Concrete Association (NPCA) Plant Certification Program

The National Pre-cast Concrete Association (NPCA) Plant Certification Program is a voluntary program through which pre-cast concrete plants can demonstrate their commitment to production of high-quality products. The basis of the NPCA certification program is the “Quality Control Manual for Pre-cast Plants” published by NPCA. The program covers all aspects of a pre-cast operation necessary for production of high-quality pre-cast concrete products and quality assurance. Compliance with the Quality Control Manual is verified with inspections of the plant on an approximately annual basis.

The program certifies that plants meeting the requirements set forth in the NPCA Quality Control Manual are capable of producing high-quality products. The main difference between the NPCA program and the ACPA program is that the NPCA program does not certify products themselves. In addition, NPCA covers all pre-cast concrete products, whereas the ACPA program focuses on concrete pipe, manholes and box culverts.

It takes about six weeks from the time when a plant's application for certification is received at NPCA, the plant is inspected, and when the plant finally receives notice of the inspection results for a plant to become certified. The initial inspection is scheduled between the plant and the inspector. Subsequent inspections are performed at each participating plant once per year on an unannounced basis.

The on-site plant audits are performed by a representative from Wiss, Janney, Elstner Associates, Inc., an independent engineering firm. This representative is responsible for scheduling and performing the inspection and then providing a report detailing the inspection findings and grade.

More information about the NPCA plant certification program can be found on the NPCA website: http://www.precast.org/certification/why_certify.htm

4.2.3 Recommendations Regarding Third Party Certification Programs for Concrete Pipe

It is recommended that the SCDOT require concrete pipe to be certified by the ACPA “Q-Cast” third party certification program. This program certifies the products and the plant; whereas the NPCA program only certifies the plant.

4.3 THIRD PARTY CERTIFICATION PROGRAMS FOR ALUMINUM PIPE

Currently there are no third party certification programs for aluminum pipe. However, Cecil Jones (NCDOT), chair of the AASHTO Subcommittee on Materials, reported at the 2005 TRB AFS04 Committee meeting that there is currently a Task Force looking into certifications for aluminum pipe.
5.0 LIFE CYCLE COST ANALYSIS

Life cycle cost analysis includes the cost of initial construction and future costs for maintenance, repair, rehabilitation and replacement over the project service life. Guidance for life cycle cost analysis is found in ASTM C1131, ASTM F1675 and ASTM A930 for reinforced concrete, high density polyethylene, and aluminum alloy pipe, respectively. The US Army Corp of Engineers’ (1998) document entitled “Engineering Design: Conduits, Culverts and Pipes” provides additional guidance. To facilitate life cycle cost analysis, the methodology in ASTM C1131 has been incorporated into software entitled “Pipe Pac-2000” by the American Concrete Pipe Association (ACPA).

5.1 STANDARD METHODOLOGY

The standard equation for Life Cycle (or Least Cost) Analysis (LCA) is as follows:

\[ \text{LCA} = C - S + \sum (M + N + R) \]

where \( C \)=original cost; \( S \)=residual cost; \( M \)=maintenance cost; \( N \)=rehabilitation cost; and \( R \)=replacement cost.

The residual cost, \( S \) is given by the following:

\[ S = C(F) \frac{n_s}{n} \]

where \( C \)=present constant dollar value; \( n_s \)=number of years service life exceeds design life; \( n \)=service life; and \( n_p \)=project design life. The inflation/interest factor, \( F \), is given by:

\[ F = \frac{(1 + I)}{(1 + i)} \]

where \( I \)=inflation rate and \( i \)=actual interest rate. The interest rate can be determined using U.S. Treasury Department values and the inflation rate can be obtained from financial forecasting such as found on www.neatideas.com. An inflation/interest factor of 0.98 is recommended by the US Army Corps of Engineers Engineering Manual (1998).

The PipePac software also calculates the following:

- initial costs or present value: \( PV = C \times F \times n \),
- future values: \( FV = PV \times (1 + i) \times n \); and
- annualized costs: \( AC = PV \times \frac{i(1 + i) \times n}{(1 + i) \times (n - 1)} \)

ASTM C1131, ASTM F1675 and A930 and the US Army Corps of Engineers Engineering Manuals (1994, 1998) provide simple examples comparing how to use the life cycle cost analysis to evaluate different materials for a given project. Where certain future costs are identical among all options, they will not affect the comparative results and may be excluded from the calculations. For example, costs might be identical for
normal operation, inspection, and maintenance. In this case, the only future costs to consider are those for major repairs and replacement. Where replacement will be necessary during the project service life, the designer must include all costs for the replacement activities. This may include significant costs for construction and traffic delays.

5.2 PRELIMINARY ANALYSIS

Preliminary life cycle costs analyses using the PipePac software were performed as part of this study. The SCDOT Materials Management Office provided the original cost values of the pipe material, but no data was available to include costs associated with original installation and future costs associated with maintenance, repair, rehabilitation or replacement. Therefore the exercise was able to evaluate the ease of use of the software, but was not able to determine the life cycle costs associated with pipe currently installed on SCDOT projects due to the lack of data.

5.3 NEED FOR DATA ON REPAIR AND MAINTENANCE COSTS

To facilitate the implementation of life cycle cost analysis, the SCDOT should document costs associated with maintenance, repair, rehabilitation and replacement. A comprehensive database on the maintenance and repair of culvert pipe should include the following:

- **Pipe details**
  - Size (diameter, length)
  - Type (Aluminum, RCP, HDPE)
  - Use (sideline, crossline, storm sewer, other)
  - Age of pipe
  - Location (county)
  - Agency responsible for installation (contractor, SCDOT maintenance, other)
  - Cost of installation

- **Repairs Made to Pipe**
  - Reason for repair
  - Type of repair made
  - Date of repair
  - Cost of repair
  - Agency responsible for repair (contractor, SCDOT maintenance, other)
  - Repair history (Has this pipe been repaired before? If so, list repairs made and dates.)
  - Expected service life of pipe

- **Maintenance Performed on Pipe**
  - Reason for maintenance
  - Type of maintenance
  - Date of maintenance
  - Cost of maintenance
  - Agency responsible for maintenance (contractor, SCDOT maintenance, other)
  - Maintenance history (Has maintenance been performed on this pipe before? If so, list type of maintenance performed and dates.)
  - Expected service life of pipe
6.0 TRAINING COURSES

Training courses were developed to educate SC DOT personnel on proper design, installation, maintenance and quality control/quality assurance of culvert pipe used in SC DOT roadway applications. Reinforced concrete, aluminum alloy and HDPE pipe materials are addressed. The courses were made in the form of Microsoft Power Point presentations.

The training courses will be delivered to the SC DOT under separate cover. The training courses will be finalized after the final report has been approved so that they include the procedures and policies implemented by the SC DOT from this report. One pilot training course will be offered to SC DOT personnel and is planned for 2006.

Seven modules were developed for the training courses. Construction and maintenance personnel will attend modules associated with pipe materials, culvert pipe selection, pipe installation and pipe maintenance. Design engineers will attend these modules as well as the module on design. The outlines of the modules developed for the SC DOT are as follows:

I. Overview of Pipe Materials
   1. Pipe Terminology
   2. Pipe-Soil Interaction
   3. Available Pipe Materials
      a. Rigid Pipe
         i. Reinforced Concrete Pipe
      b. Flexible Pipe
         i. Corrugated Aluminum Alloy Pipe
         ii. High Density Polyethylene Pipe

II. Culvert Pipe Selection Guide
   1. Acceptable Pipe Material Types Based on Use and Design Life
   2. Hydraulics
   3. Corrosion and Abrasion Analysis
   4. Structural Analysis
   5. Life Cycle Costs
   6. Reference Specifications

III. Overview of Site Investigation and Installation Procedures
   1. Site Conditions
      a. Site and Environmental Conditions
      b. Soil and Effluent Tests
      c. Soil Types
      d. Soil Classification
      e. Soil Density
   2. Materials Management
      a. Delivery
      b. Handling
      c. Storage
   3. Construction of Pipe-Soil System
      a. Standard Installation
         i. Trench Excavation
         ii. Foundation
iii. Bedding  
iv. Laying Pipe  
v. Joining Pipe  
vi. Compaction  
vii. Embedment  
viii. Backfill  
ix. Minimum Cover  
b. Installation Considerations

4. Post Installation Inspection  
5. Safety Gear  
6. Utilities  

IV. Installation of Reinforced Concrete Pipe  
1. Description of Pipe Material  
a. SCDOT Approved Applications  
b. Material Specifications  
c. Pipe Properties  
d. Markings/Certifications  
e. Pipe Inspection at Plant/Site  
f. Pipe Delivery  
2. Storage and Handling  
3. Installation  
a. Specifications  
i. Bedding/Backfill Type  
ii. Trench Dimensions  
b. Methods  
i. Excavating the Trench  
ii. Foundation  
iii. Bedding  
iv. Laying the Pipe  
v. Pipe Alignment  
vi. Joining Pipe  
vii. Embedment  
viii. Compaction  
x. Backfill Minimum/maximum cover  
x. Saturated Conditions/migration of fines (filter fabric)  
xi. Manhole connections  
4. Pipe Ends  
a. Pipe end protection  
b. Pipe end sections  
c. Concrete pad, rip rap, and manufactured end sections  
5. Post Installation Inspection  
a. Damage Types  
b. Joints and Alignment  

V. Installation of High Density Polyethylene Pipe  
1. Description of Pipe Material  
a. SCDOT Approved Applications  
b. Material Specifications  
c. Pipe Properties  
d. Markings/Certifications  
e. Pipe Inspection at Plant/Site  
f. Pipe Delivery  
2. Storage and Handling
3. Installation
   a. Specifications
      i. Bedding/Backfill Type
      ii. Trench Dimensions
   a. Methods
      i. Excavating the Trench
      ii. Foundation
      iii. Bedding
      iv. Laying the Pipe
      v. Pipe Alignment
      vi. Joining Pipe
      vii. Embedment
      viii. Compaction
      ix. Backfill Minimum/maximum cover
      x. Saturated Conditions/migration of fines (filter fabric)
     xi. Manhole connections
4. Pipe Ends
   a. Approved methods for cutting pipe
   b. Pipe end protection
   c. Pipe end sections
   d. Concrete pad, rip rap, and manufactured end sections
5. Downdrains and Slopedrains
6. Post Installation Inspection
   a. Damage Types
   b. Deflection Testing
   c. Joints and Alignment

VI. Installation of Corrugated Aluminum Pipe
1. Description of Pipe Material
   a. SCDOT Approved Applications
   b. Material Specifications
   c. Pipe Properties
   d. Markings/Certifications
   e. Pipe Inspection at Plant/Site
   f. Pipe Delivery
2. Storage and Handling
3. Installation
   a. Specifications
      i. Bedding/Backfill Type
      ii. Trench Dimensions
   a. Methods
      i. Excavating the Trench
      ii. Foundation
      iii. Bedding
      iv. Laying the Pipe
      v. Pipe Alignment
      vi. Joining Pipe
      vii. Embedment
      viii. Compaction
      ix. Backfill Minimum/maximum cover
      x. Saturated Conditions/migration of fines (filter fabric)
     xi. Manhole connections
4. Pipe Ends
   a. Pipe end protection
   b. Pipe end sections
5. Post Installation Inspection  
   a. Damage Types  
   b. Deflection Testing  
   c. Joints and Alignment

VII. Design of Buried Pipe  
1. Types of Pipe and Soil  
   a. Types of Pipe and their Materials  
      i. Design Forces in Buried Pipes  
         1. Rigid Pipe  
         2. Flexible Pipe  
   b. Site and Environmental Conditions  
      i. Local Conditions  
      ii. Adverse Conditions  
   c. Characteristics of Soil Types  
      i. Soil Type  
      ii. Soil Classification  
      iii. Soil Density  

2. Principles of Pipe-Soil Interaction  
   a. Loads on Buried Pipes  
      i. Rigid Pipe  
      ii. Flexible Pipe  
   b. Distribution of Load on Pipe  
      i. Rigid Pipe  
      ii. Flexible Pipe  
   c. Laboratory Tests  
   d. Design of Rigid Pipe  
   e. Design of Flexible Pipe  
   f. Pipe Bedding and how it affects Pipe Performance

In addition to these modules, the training courses will include showing the video entitled “Design and Installation of Buried Pipes” (McGrath and Howard, 1998) published by ASCE. The video gives a general overview of the design and installation of buried pipe.
7.0 PROJECT SUMMARY

This report presented the findings from a study undertaken to improve the field performance of reinforced concrete, aluminum alloy and high density polyethylene culvert pipe used in SCDOT roadway applications. The work resulted in the development of a “SCDOT Culvert Pipe Selection Guide” and has provided guidance on the recommended practices for proper design, installation and quality control/quality assurance for product approval and field inspection of delivered pipe and installation procedures. Recommendations have been made to modify the SCDOT Standard Specifications for Highway Construction and other SCDOT documents to properly address the design, installation and inspection of culvert pipe. The final product of this work was the development of a training course to educate SCDOT personnel on the proper design, installation, maintenance, and quality control/quality assurance of culvert pipe used in roadway applications.

7.1 RECOMMENDATIONS

The following recommendations are made based on the findings presented herein:

1. Implement the “SCDOT Culvert Pipe Selection Guide” presented in Section 2. As part of the implementation, the SCDOT will need to determine the division of responsibility. For example, for design projects, the Hydraulics Design Group should be responsible for determining the required pipe diameter for a given site and the Roadway Structures Group should be responsible for the structural analysis (e.g. cover height, backfill type and compaction, trench width and depth). The Roadway Structures Group will need to work with the Office of Materials and Research to determine who will be responsible for collecting the data on the environmental conditions of the soil and water at a site.

2. Implement good quality control/quality assurance practices to assure the quality of the pipe-soil system. Pipelines must be properly designed, constructed and installed to ensure long-lasting performance and meet the expected service life.

3. Improve installation standards for all pipe material types based on the guidelines and resource documents presented in Section 3.

4. Improve the quality and density of backfill materials placed around pipe. For SCDOT applications that require at least a 75 year service life (“freeways” as defined by the SCDOT Highway Design Manual (2003)) shall use a well-graded sand or gravel meeting the requirements of GW or SW material (ASTM 2487) or A-1 (AASHTO M 145)) for the bedding and backfill. Uniformly graded coarse-grained soils (GP, SP and A-3) can be used if provisions are made to evaluate and control possible migration of fines into open voids. Conduits under roadways having a 50 year service life (“rural highways”, “suburban and urban streets,” “local roads and streets” as defined by the SCDOT Highway Design Manual (2003)) shall use coarse grained soils with fines or fine grained soils with at least 50% coarse grained material and low to no plasticity (GC, GM, SC, SM, A-2-4 and A-2-5) if compaction requirements are strictly enforced. Backfill shall be compacted to at least 95% of maximum standard Proctor density per AASHTO T 99. Storm sewers outside of pavements (50 year service life) or
applications that require a 25 year service life (side drains, driveways and conduits outside of pavements) may use any of the materials above as well as fine grained soils with low to medium plasticity (CL, ML, GC, SC or A-2-6, A-2-7, A5, A6) compacted to at least 95% of maximum standard Proctor density per AASHTO T 99.

5. Improve the compaction inspection standards by performing density checks on compacted backfill using a geogage or nuclear density gage to verify that adequate compaction has been achieved. In addition, contractors should furnish similar quality control data to the SCDOT. Density checks should be made at the springline of the pipe to ensure that compaction is adequate in the haunches, where it is most critical. A minimum compaction level of 95% Standard Proctor density is required to meet the 75 year service life requirement for freeways and 50 year service life for other conduits under roadways.

6. Require all pipes to meet minimum cover requirements. Concrete elliptical pipe and aluminum pipe arch are good alternatives to circular pipe when additional room for cover is needed.

7. Require end treatments on all cross drain, side drain, or storm sewer pipe ends. End treatments can be constructed of riprap or consist of beveled ends with concrete pads.

8. Improve inspection standards for all installed pipes. Visually inspect all installed pipe to ensure proper joining, line and grade of pipe. Large diameter pipe can be inspected by walking the length of the pipe; whereas small diameter pipes require the use of video camera equipment with a laser deflection measuring device attached.

9. Ensure that deflection criteria are met for flexible pipe. For construction projects, the contractor should verify that the installed pipe meets the minimum deflection criteria by performing the mandrel test or using a laser deflectometer. For quality assurance on construction projects, the SCDOT Office of Materials and Research should perform random deflection tests. On maintenance projects, the SCDOT Office of Materials and Research should perform the test.

10. Require random inspection of pipe throughout the construction process to prevent poor construction methods from propagating through entire projects.

11. Utilize third party certification and testing programs for quality control and quality assurance. For quality control of HDPE pipe, it is recommended that the SCDOT require HDPE pipe to be certified by the PPI or NTPEP third party certification programs to qualify for inclusion on Approval Sheet 30 as approved manufacturers of HDPE pipe. When NTPEP becomes more established, this recommendation should be revisited. For quality assurance, the SCDOT should use the NTPEP program for Quality Assurance testing. Samples of product can be randomly selected for confirmation testing by the NTPEP participating test facilities. For quality control of concrete pipe, it is recommended that the SCDOT require concrete pipe to be certified by the ACPA “Q-Cast” third party certification program. The SCDOT should continue their current practice of plant and pipe inspections for quality assurance. In the current absence of third party testing for aluminum alloy pipe, the SCDOT, through its membership on AASHTO subcommittees, should encourage the aluminum alloy pipe industry to develop a third party testing program for quality control. In addition they should
encourage NTPEP to expand its program to include a quality assurance testing program for aluminum alloy pipe.

12. Require a minimum joint performance of “soil tight.” Consider revising the current pipe joining requirements based on results of the current study being performed by the AASHTO Subcommittee on Materials.

13. Perform a field study to evaluate aluminum alloy pipe with rerolled ends for possible inclusion in approved joining list.

14. Conduct a research project to develop a historical database for soils that include soil types, soil pH, and soil resistivity across the state. Similar studies should be performed on effluent, especially in agricultural areas.

15. Compile a database containing the history and cost of pipe maintenance and repair for use in life cycle cost analysis.

16. Initiate a pipe users group similar to FLDOT’s “Pipe Advisory Group”. This can provide an avenue for those interested in drainage pipe (DOT personnel, manufacturers, etc) to openly discuss pipe materials in the presence of representatives of all pipe material types. Such a group should meet quarterly.

17. Continue to evaluate appropriate joint requirements for all pipe types. Follow the recommendations of the current AASHTO Subcommittee on Materials study when they are released.

18. Continue to evaluate the appropriate deflection limit for aluminum pipe. The rationale for setting either a 5%, 7.5% or a 10% deflection limit for metal pipe is still being studied by others.

7.2 SUGGESTED REVISIONS TO SECTION 714 OF THE SCDOT STANDARD SPECIFICATIONS FOR CONSTRUCTION

The following is an itemized list of some recommended revisions to Section 714 of the SCDOT Standard Specifications for Highway Construction. The SCDOT should consider these and additional revisions based on the findings in this report as deemed necessary. Section 714 of this document is reproduced in Appendix A. Each revision is noted numerically (e.g. (1)) within the text of the specifications and corresponds to the following notes:

(1) Note: The “SCDOT Pipe Selection Guide” requires two hydraulic designs if more than one material type is acceptable for a given project: one using a Manning’s roughness coefficient associated with concrete, spiral rib, and polyethylene pipe and one using a Manning’s roughness coefficient associated with corrugated aluminum alloy pipe.

Add: “When more the one pipe material is acceptable for a given project, two pipe diameters will be shown on the plans at those locations. The first dimension will indicate the diameter of pipe that shall be provided if the contractor elects to provide pipe for that location with a smooth interior wall (reinforced
concrete pipe, high density polyethylene pipe and Spiral Rib aluminum pipe – Type IR), and the second
dimension provided in parenthesis will indicate the diameter of pipe that shall be provided if the
contractor elects to provide pipe for that location with a corrugated wall (corrugated aluminum alloy
pipe). Regardless of which diameter of pipe is selected for a given location, the pipe flow line shall be
maintained at the elevations shown on the plans.”

(2) Add: “All reinforced concrete pipe shall be certified by ACPA “Q-Cast”.

(3) Add: “The shipped pipe shall be identified by the identification of the pipe fabricator; the fabricator’s
date of forming into pipe by a six-digit number indicating in order the year, month, and day of the month;
and AASHTO designation number M 196. The corrugated sheet shall be identified by the name or
trademark of sheet manufacturer; alloy and temper; specified thickness; date of corrugating by a six-digit
number indicating in order the year, month, and day of the month; and AASHTO designation number M
197. The shipped fittings shall be plainly marked with the manufacturer’s identification symbol and
specification designation “AASHTO M 196”.”

(4) Replace “ (12 Inch Diameter and Greater)” with“(12 to 60 Inch Diameter)”

(5) Add: “All HDPE pipe must be certified by the PPI or AASHTO NTPEP third party certification
programs.”

(6) Change: “The shipped pipe and fittings shall be plainly marked with the manufacturer’s name, trademark
and type of pipe as specified in AASHTO M 294.”

to

“The shipped pipe shall be plainly marked with the manufacturer’s name, trademark, nominal size,
specification designation “AASHTO M 294”, plant designation code, the date of manufacture or an
appropriate code, and certification stamp from PPI or NTPEP. The shipped fittings shall be plainly
marked with the manufacturer’s identification symbol and specification designation “AASHTO M 294”.”

(7) Add: “The minimum trench width should not be less than the greater of the pipe outside diameter plus 18
in. or the pipe diameter times 1.5 plus 12 in. With CLSM backfill, the trench width may be a minimum of
the outside diameter plus 12 in.”

(8) Note: There are two ways to cradle pipe. It is imperative that the pipe be cradled to provide proper
support.
Change: “the trench bottom shall be carefully shaped to fit the bottom of the pipe for a depth of a least 10% of its overall height and bedding shall have recesses shaped to fit any projected hubs or bells.”

to

“The pipe shall be cradled in one of two ways: 1) Bedding under the pipe for the central one-third of the pipe outer diameter shall be placed loosely and left uncompacted for a depth of 10% of the pipe diameter or 2) the compacted trench bottom shall be carefully shaped to fit the bottom of the pipe for a depth of a least 10% of its overall height. In all cases, bedding shall have recesses shaped to fit any projected hubs or bells.”

(9) Change “overall height” to “overall diameter”

(10) Change: “The width of the excavation shall be 12 inches greater than the outside diameter of the pipe and shall be refilled with suitable material and compacted and shall be shaped to form a firm uniform bed.”

to: “The excavated material shall be replaced with suitable material and compacted and shall be shaped to form a firm uniform bed and cradle the pipe.”

(11) Note: McGrath (2003) developed the following trench width and trench box specification that is appropriate for SCDOT projects. Therefore, add the following:

Add: “If the trench walls do not stand without support, then increase the trench width to provide a minimum of one half diameter width of structural backfill on either side of the pipe. (This pertains to structural support and does not include support supplied solely for worker safety in trenches)

When supports such as trench boxes are used, ensure that support of the pipe and its embedment are maintained throughout the installation. Ensure that sheeting is sufficiently tight to prevent washing out of native soil from behind the trench box.

Do not disturb the installed pipe and its embedment when moving trench boxes. Trench boxes should not be used below the top of the pipe zone unless methods approved in advance are used for maintaining the integrity of the embedment material. As the supports are moved, any voids left by the trench walls below the top of the pipe zone must be filled with specified structural backfill, compacted per these specifications.”

Workers in the trench must stay within the trench box and follow all OSHA regulations.

(12) Add: “Minimum joint requirements for all pipe are soil-tight.”
Add: “All pipe applications that require at least a 75 year service life (“freeways” as defined by the SCDOT Highway Design Manual (2003)) shall use a well-graded sand or gravel meeting the requirements of GW or SW material (ASTM 2487) or A-1 (AASHTO M 145)) for the bedding and backfill. Uniformly graded coarse-grained soils (GP, SP and A-3) can be used if provisions are made to evaluate and control possible migration of fines into open voids.

Conduits under roadways having a 50 year service life (“rural highways”, “suburban and urban streets,” “local roads and streets” as defined by the SCDOT Highway Design Manual (2003)) shall use coarse grained soils with fines or fine grained soils with at least 50% coarse grained material and low to no plasticity (GC, GM, SC, SM, A-2-4 and A-2-5) if compaction requirements are strictly enforced. Backfill shall be compacted to at least 95% of maximum standard Proctor density per AASHTO T 99.

Storm sewers outside of pavements (50 year service life) or applications that require a 25 year service life (side drains, driveways and conduits outside of pavements) may use any of the materials above as well as fine grained soils with low to medium plasticity (CL, ML, GC, SC or A-2-6, A-2-7, A5, A6) compacted to at least 95% of maximum standard Proctor density per AASHTO T 99.

Controlled low strength material (CLSM) and controlled density fill (CDF) are flowable fills which may be used for bedding and backfill. Flowable fill mix design should be selected so that the material is excavatable. With CLSM backfill, the trench width shall be a minimum of the outside diameter plus 12 in. When CLSM is used, the pipe cannot be perforated and all joints should have gaskets. Restraint shall be provided to prevent pipe flotation.”

Add: “Trenches must be free of water when placing and compacting backfill.”

Add: “The height of the first lift must be sufficiently below the spring line such that material can be worked into the haunch zone of the pipe.”

Change: “Care shall be exercised to thoroughly compact the backfill under the haunches of the pipe and to insure that the backfill soil is in intimate contact with the side of the pipe.”

to

“The material placed under the haunches of the pipe must be thoroughly compacted and in intimate contact with the side of the pipe. Care shall be exercised to avoid damaging or misaligning the pipe with the compaction equipment.”
(17) Remove this paragraph. This procedure is not acceptable for flexible pipes and is questionable for rigid pipes.

(18) Add: For all pipe installations, SCDOT shall be furnished with quality control data to verify that compaction requirements have been met. Density checks should be made at the springline of the pipe.

(19) Specifications should include requirements for minimum and maximum fill heights. Add the following:

“714.xx Cover Height. The minimum height of cover for all pipe shall be in accordance with the height of cover tables in the “SCDOT Culvert Pipe Selection Guide.” Concrete elliptical pipe and aluminum pipe arch are good alternatives to circular pipe when additional room for cover is needed.

The maximum height of cover shall be in accordance with the height of cover tables in the “SCDOT Culvert Pipe Selection Guide.””

“714.xx Construction Loads. During construction of all pipe culverts, a greater minimum fill height is required. No heavy equipment shall be driven over any pipe culvert until the backfill is completed to the minimum allowable cover height for construction loading as presented in the “SCDOT Culvert Pipe Selection Guide” so that damage does not occur to the pipe. This minimum cover must be maintained until heavy equipment usage is discontinued. Any damage or displacement shall be repaired or corrected at the contractor’s expense.”

(20) Add:

714.xx Installation Inspection. All concrete, aluminum and HDPE pipe shall be inspected with video camera inspection equipment with laser deflectometers to ensure proper joining, line and grade of pipe. Inspections shall be conducted no sooner than 30 days after completion of installation and final fill.

For concrete pipe, when signs of distress, such as differential movement, efflorescence, spalling, rust stains or cracks wider than 0.01 in. are present in the pipe, an evaluation shall be conducted by the Contractor and submitted to the SCDOT Engineer for review and approval considering the structural integrity, environmental conditions, and the design service life of the pipe. Cracks having widths equal to or greater than 0.01 in. and determined to be detrimental shall be sealed by a method approved by the SCDOT Engineer. Pipes with cracks having widths greater than 0.1 in. and determined by the SCDOT Engineer to be beyond satisfactory structural repair shall be remediated or replaced. Pipes
having displacement across the crack shall be repaired or replaced. Pipes experiencing spalls or delaminations shall be repaired or replaced.

For HDPE pipe, when installed pipe deflections exceed 5 percent of the inside diameter, an evaluation shall be conducted by the Contractor and submitted to the SCDOT Engineer for review and approval considering the severity of the deflection, structural integrity, environmental conditions, and the design service life of the pipe. Pipe remediation or replacement shall be required for locations where the evaluation finds that the deflection could be problematic. For locations where the installed pipe deflections exceed 7.5 percent of the initial inside diameter remediation or replacement of the pipe shall be required.

For aluminum pipe, when pipe distress such as cracking along bolt holes, wall damage (dents, bulges, creases, cracks and tears) and excessive deflection or poorly shaped cross-section are present in the pipe, an evaluation shall be conducted by the Contractor and submitted to the SCDOT Engineer for review and approval considering the structural integrity, environmental conditions, and the design service life of the pipe. Pipe remediation or replacement shall be required for locations where the evaluation finds that the distresses could be problematic.

(21) Add:

**714.xx Handling and Storage.** Pipe must be handled and stored such that no damage occurs to the pipe. The unloading site must be relatively flat and level, free of debris, and out of the way of construction traffic. Pipes, fittings and other components must be lifted and moved safely with the aid of appropriate unloading and handling equipment. For pipes with attached bells, the direction of the pipe lengths shall be alternated so that the bells are not stacked on top of each other. Up to three pipes can be laid before alternating direction.
8.0 BIBLIOGRAPHY


ACPA (1995). *Concrete Pipe Installation*, American Concrete Pipe Association, Irving, TX.


ACPA (2001). *Selected ASTM Standards on Concrete Pipe*, American Concrete Pipe Association Irving, TX.


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APPENDIX A
Suggested Revisions in Section 7.2
Note: Recommended revisions are labeled (1) to (21)

SECTION 714

PIPE CULVERTS

714.01 Description. This work shall consist of furnishing pipe of the size, shape, type, and dimensions indicated on the plans and installing them to provide drainage structures at places designated on the plans or by the Engineer in accordance with these specifications and true to the lines and grades shown on the plans or otherwise given by the Engineer. This work shall include the furnishing and installing of necessary tee, wye, elbow and bend joints, and making connections to existing and/or new structures, including drilling and chipping as may be necessary to complete the work.

MATERIALS

714.02 General. Only materials specified herein shall be used for the several items that constitute the finished pipe culvert.

714.03 Circular Reinforced Concrete Culvert Pipe. Circular RC culvert pipe shall conform to the applicable requirements of AASHTO M 170, (ASTM C 443) and the Policy for Inspection and Acceptance of Concrete Culvert Pipe adopted by the Department for the specified diameters, shapes, types, and strength classes, except for the modifications stated herein. When a strength class is not specified, Class III pipe shall be used. The pipe shall be furnished in manufactured lengths from 4 to 12 feet. Circular pipe sizes through 36 inches diameter shall have the standard circular reinforcement conforming to the requirements of AASHTO M 170.

Reinforcement for circular pipe sizes 42 inches in diameter or larger may contain any of the reinforcement designs conforming to the requirements of AASHTO M 170. When
other than circular designs are used, the pipe joint shall have a lift hole established in the top of the shell and be marked “Top.” The special design reinforcement shall be placed in position and stabilized by satisfactory means to assure that it will not shift or rotate during the manufacturing process.

For classes and sizes of circular, or elliptical pipe with reinforcement designs not shown in AASHTO M 170, or M 207, respectively, the manufacturer shall submit to the Engineer a design that will meet the strength requirements for the specified pipe.

Portland cement shall conform to the requirements of Subsection 701.02.

Fly ash and water-granulated blast-furnace slag may be used at the option of the manufacturer in accordance with the following requirements:

1. Fly ash shall meet ASTM C 618 for Type F or C with a maximum Na₂O of 1.5%. Water-granulated blast-furnace slag shall meet the requirements of ASTM C 989, Grade 120.

2. The amount of cement to be replaced by fly ash shall not exceed 15% and the amount to be replaced by water-granulated blast-furnace slag shall not exceed 50%. Fly ash shall replace the cement in the ratio of not less than 1.2 to 1 by weight. Water-granulated blast-furnace slag shall replace the cement in the ratio of not less than 1:1 by weight.

3. Fly ash and slag will be accepted only from approved sources. Certified mill test reports shall be furnished with each shipment to verify compliance requirements.

4. The manufacturer shall submit a mix design to the Engineer for his approval in advance of batching. The submittal shall indicate the amount of
cement to be removed and the material that will replace it.

5. Storage bins, conveying devices and weighing equipment and procedures to assure accurate batching shall be provided for each material (fly ash or slag) to be used.

Aggregates shall conform to the quality requirements as specified in Section 701 for aggregates. Gradation of the aggregates shall be at the option of the manufacturer.

Steel reinforcement shall conform to the requirements of AASHTO M 31, M 32, M 55, M 221, or M 225 as applicable.

Gasket seals shall be flexible watertight gaskets conforming to AASHTO M 198, Type A, or Type B. Type B gasket seals shall be of the minimum size to produce a watertight joint in the annular space of the pipe being used. Only those gasket sources which appear on an approved list, published by the South Carolina Research and Materials Laboratory, entitled Approved Preformed Flexible Plastic Gaskets shall be used. Approval may be obtained by furnishing the Research and Materials Engineer a certified affidavit with test results made in a recognized laboratory confirming that the material meets AASHTO M 198 along with complete instructions for installation of the material.

Water shall meet the requirements of Subsection 701.12.

714.04 Elliptical Reinforced Concrete Culvert Pipe. Elliptical RC culvert pipe shall meet the applicable requirements of Subsection 714.03. The thickness and dimensions of the pipe shall be in accordance with the plans.

714.05 Corrugated Steel Culvert Pipe. Corrugated steel culvert pipe shall meet the requirements of AASHTO M 36. Where elliptical pipe is called for on the plans or in the special provisions, the pipe shall be distorted from a true circle to provide an increase in the vertical diameter of approximately
5%. Distortion shall be performed at the fabricating shop. The thickness of the pipe shall be in accordance with the plans.

714.06 Corrugated Steel Culvert Pipe-Arch. Corrugated steel culvert pipe-arch shall conform to the requirements of AASHTO M 36, Type II.

Dimensions shall be in accordance with Table 4 of AASHTO M 36, Type II and shall be measured from the inside crest of the corrugations. Metal thickness of the pipe arch shall be in accordance with the plans.

End sections shall be fabricated from materials conforming to the applicable requirements of AASHTO M 218. Metal thickness of the end section shall be in accordance with the plans.

714.07 Bituminous Coated Corrugated Steel Culvert Pipe and Pipe-Arch. Bituminous coated corrugated steel culvert pipe and pipe-arch shall conform to the requirements of Subsections 714.05 and 714.06 and AASHTO M 190, Type A, Type B, or Type C. The pipe or pipe-arch shall be coated with bituminous materials as hereinafter described for the particular type specified.

Type A, Fully Bituminous Coated Culvert Pipe, shall be uniformly coated with bituminous material, inside and outside, to a minimum thickness of 0.05 inch, measured on the crests of the corrugations.

Type B, Half Bituminous Coated and Paved Culvert Pipe, shall be uniformly coated for approximately one-half of the circumference of the pipe (bottom of the pipe installed), inside and outside to a minimum thickness of 0.05 inch and in addition, the bituminous material shall be applied in such a manner that one or more smooth pavements will be formed in the invert (inside bottom of the pipe when installed), filling the corrugations for at least 25% of the circumference of a pipe and 40% of the circumference of a pipe-arch. The pavement
shall have a minimum thickness 1/8 inch above the crest of the corrugations, except where the upper edges intersect the corrugations.

Type C, Fully Bituminous Coated and Paved Culvert Pipe, shall be fully coated as required for Type A above and in addition, a smooth pavement shall be provided as required for Type B above.

714.08 Corrugated Aluminum Alloy Culvert Pipe and Pipe-Arch. This pipe shall conform to AASHTO M 196. The thickness of the pipe shall be in accordance with the plans.

714.09 Corrugated High Density Polyethylene Culvert Pipe (12 Inch Diameter or Greater). This pipe shall conform to the requirements of AASHTO M 294, Type C or Type S, as required.

Type C pipe shall have corrugated, high density surface both inside and outside, and shall only be used in temporary applications.

Type S pipe shall have an outer corrugated high density pipe wall and a smooth inner liner, and shall be the only type used in permanent applications.

Only materials from sources appearing on the Department's approved list entitled "Corrugated High Density Polyethylene Pipe Sources" shall be used in the work. A copy of this approval list of sources may be obtained from the Department's Research and Materials Engineer. A manufacturer may request to be included on the approval list by furnishing certified test results from an independent laboratory verifying that the proposed pipe design meets or exceeds the requirements of this specification. The request must also include a certification of materials. Further, the manufacturer shall furnish complete instructions as to installation along with technical data sheets and materials safety data sheets. The approval process may require a demonstration
of installation procedures and an in-plant inspection of quality control procedures.

After source approval, the manufacturer shall furnish with each shipment of materials a certification showing brand name, S.C. File Number for the project, the shipping date and to whom it is shipped, and the quantity and size of pipe represented. The certificate shall contain a statement that the material meets the South Carolina Department of Transportation specifications and is essentially the same as that approved by the Department. The shipped pipe and fittings shall be plainly marked with the manufacturer's name, trademark and type of pipe as specified in AASHTO M 294. A materials safety data sheet and installation instructions shall be furnished with each shipment.

Changes in design and/or materials after initial source approval shall be submitted to the Engineer for evaluation.

CONSTRUCTION REQUIREMENTS

714.10 Trench and Bed for Pipe. The pipe shall be laid in a trench where possible. Trenches shall be excavated to the required grade and to a width sufficient to allow for proper jointing of the pipe and for thorough compaction of the backfill material under and around the pipe. The trench bottom shall give full support to the pipe throughout its length. The trench bottom shall be carefully shaped to fit the bottom of the pipe for a depth of at least 10% of its overall height and shall have recesses shaped to fit any projecting hubs or bells.

Where pipe culverts are to be placed in new embankments, the embankments shall first be constructed to a height of approximately 1/2 the diameter of the pipe above the top of the designated pipe or to such height as directed by the Engineer. The embankment shall be constructed for a distance of not less than 5 times the diameter of the pipe on each side of the pipe location, after which the trench shall be excavated in the embankment as described above.
When a firm foundation is not encountered at the required grade, all such unstable material under the pipe and for a width of at least one diameter on each side of the pipe, except where widths are restricted by obstructions, shall be removed and the resulting excavation backfilled with suitable material and compacted and shall be shaped as described above.

When excavating for pipe culverts, if rock, hard pan, or other unyielding foundation material is encountered, the hard unyielding material shall be excavated below the elevation of the bottom of the pipe or pipe bell to a minimum depth of 8 inches. The width of the excavation shall be 12 inches greater than the outside diameter of the pipe and shall be refilled with suitable material and compacted and shall be shaped to form a firm uniform bed.

The Contractor shall provide, as may be necessary, for temporary diversion of water or pumping in order to permit the installation of the culvert in the dry. All trenches shall be kept free from water until any joint sealant material has hardened sufficiently not to be harmed.

If desired by the Engineer, the grade of the foundation shall be cambered by an amount sufficient to prevent the development of a sag in the flow line as the foundation soil settles under the weight of the embankment. In no case shall the camber be sufficient to produce an adverse grade after settlement has occurred.

**714.11 Laying Pipe.** Each section of pipe shall have a full firm bearing throughout its length, true to line and grade given. Any pipe which settles before final acceptance or which is not in alignment shall be taken up and re-laid by the Contractor without extra compensation. Pipe laying shall begin at the downstream end of the culvert with the bell or groove ends and outside laps upstream.

When concrete elliptical pipe with circular reinforcement or
concrete circular pipe with elliptical or quadrant reinforcement is used, the pipe shall be installed in such a position that the manufacturer’s marks designating the top or bottom of the pipe shall be not more than 5 degrees from the vertical plane through the longitudinal axis of the pipe.

Prior to being lowered into the trench, corrugated metal pipe sections shall be closely examined and so fitted that they will form a true line of pipe when in place. Sections that do not fit together properly shall not be used. Corrugated metal pipe shall be laid with the lap down stream.

Distorted circular metal pipes shall be placed with the major axis vertical. If rods, struts, or other means are used to maintain pipe distortion, they shall not be removed before the completion of the embankment unless otherwise permitted by the Engineer.

Before laying the pipe or during the pipe laying operations, adequate outfall ditches and inlets free of obstructions shall be constructed in order that proper drainage is provided.

When pipes are protected by endwalls or connect with drainage structures, the exposed ends shall be placed or cut off flush with the interior face of the structure. Where pipe culverts are constructed in conjunction with existing structures, satisfactory connections shall be made as directed by the Engineer.

714.12 Joints. All concrete pipe shall be laid with cement mortar joints or approved preformed flexible watertight gaskets. The mortar mixture shall be one part portland cement and two parts approved clean sand by volume. The quantity of water in the mixture shall be sufficient only to produce a stiff, workable mortar and shall not exceed 5 1/2 gallons of water per bag of cement. The pipe ends shall be thoroughly cleaned and wetted with water before the joint is made. Stiff mortar shall then be placed in the lower half of the bell or groove of the pipe section already laid.
Next, mortar shall be applied to the upper half of the spigot or tongue of the pipe section being laid. Then the spigot end of the pipe section shall be inserted in the groove end of the pipe section already laid, the joint pulled up tight so that the joint shall be pressed full. Care shall be taken to see that the inner surfaces of the abutting pipe sections are flush and even. After the section is laid, the inner circumference of the joints shall be sealed and packed with mortar and finished smooth and flush with the adjacent section of pipe. Additional mortar shall be applied from the outside and forced into the unfilled portion of the bell or groove to fill completely the annular space around the spigot or tongue. Mortar joints shall be made with an excess of mortar to form a bead around the outside of the conduit. Pipes more than 36 inches in diameter shall have beads of not less than 4 inches wide nor less than 2 inches thick. The completed joints shall be protected against rapid drying by suitable covering material. The backfilling operation shall be performed in such manner as not to disturb the mortared joints. After placement of the earth fill, any joints found not filled with mortar due to settlement, or other reasons shall be finished smooth and even with the inside surface of the pipe.

Instead of the mortar mix type joints, the Contractor, at his option, may seal the culvert joints using flexible soil-tight gaskets conforming to the requirements of AASHTO M 198. The gaskets shall be continuous in the joint and shall be of the minimum size to produce a soil-tight joint in the annular space of the culvert. The gasket diameter may be varied by the Engineer to require enough seal or to prevent waste of the gasket material. When the culvert is in place, the gasket seal should be visible on the inside or the outside (not necessarily both) depending on where it was placed before the culvert joints were jointed. When seal is observed to be squeezing out of the inside or outside of the culvert joints in excess, special attention shall be given to the placing of the gasket on the section tongue to prevent this. In the event the seal is observed squeezing out on the inside and outside in excess, the gasket diameter may be reduced to prevent waste of seal material.
All culvert joints shall be forcefully pressed together to form a durable soil-tight joint. In all cases, the culvert joints shall be dry from all forms of moisture and free from dust and contaminants before the gasket is placed on the section tongue. The culvert trench shall be free from standing water and mud when section is being placed. Type A gaskets shall not be stretched more than 20% of the original circumference when seated on the spigot or tongue of the section. Type B gaskets may consist of one or more pieces and shall be used without stretching.

Corrugated high density polyethylene pipe joints may be the bell and spigot type that ensures a soil-tight joint. A bell may be manufactured either as part of the pipe on one end or separately from the pipe with materials as specified in AASHTO M 294. The bell, if manufactured separately from the pipe, shall be attached to the pipe when shipped. All joints shall be provided with gaskets. Gaskets shall be preinstalled on the spigot end of the pipe or inside of the bell and covered with a removable wrap. Gaskets shall be manufactured in accordance with the requirements of ASTM F 477 and shall not have any visible cracking when tested according to ASTM D 1149. Split couplers are not approved for use.

At the Contractor’s option, corrugated high density polyethylene pipe joints may be installed with reinforced mastic couplers that assure a soil-tight joint. The coupler shall consist of a band of cross laminated polyethylene with the underside coated with a rubberized mastic reinforced with a heavy woven polypropylene fabric. There shall be a peelable protective film against the exposed mastic that shall be removed when the coupler band is applied to the pipe joint. Three nylon straps, 1/2 inch wide and a minimum strength of 600 pounds each, shall be located within the mastic between the outer polyethylene layer and the reinforcing polypropylene layer. The straps shall be sheathed in tubes that isolate them from the mastic, thus allowing them to slip freely when tightened around the pipe joint. The width of the coupler band shall be determined by the pipe diameter and the spacing of
the corrugations. The straps shall be spaced within the coupler to correspond to the spacing of the corrugations on the pipe. The length of the coupler band shall be the length of the outside circumference of the pipe joint plus a minimum 8 inch overlap.

When the pipe sections to be joined are butted end to end, the reinforced mastic coupler, with the protective film removed, shall be placed around the pipe, spanning the joint with the exposed mastic against the pipe. The center strap within the coupler and shall be aligned over the butted pipe ends while the two outside straps shall be aligned with the first corrugation groove on each side. The ends of the band shall be overlapped at the top of the pipe. The two outside straps shall be secured tightly around the joint with a proper tensioning tool and buckles. Only after the two outside straps are secure, the center strap shall be tightened and secured. The remaining flap, with the protective film removed, shall cover the exposed strap and working area.

In addition to be used as an alternative to bell and spigot joints, reinforced mastic couplers may be used to join corrugated pipe with dissimilar corrugation configurations, or to join pipe of dissimilar materials.

Corrugated steel and aluminum pipe and ribbed aluminum pipe may be joined with coupling bands. The coupling band shall be fully corrugated of like material to match the same type of corrugation as the pipe that the band will join together. Pipe ends will not be re-rolled to form annular corrugations on helical pipe. Coupling bands shall conform to the requirements of AASHTO M196 excepted for the following: Coupling bands with projections (i.e. dimples) will not be permitted. Coupling bands shall have closed cell expanded rubber gaskets to insure a soil tight joint. The gaskets shall be 12 inches wide and approximately 3/8 inch thick. Rubber O-ring gaskets will not be allowed. Bolts for all size bands shall be 0.5 inch in diameter with nuts, and shall conform to the re-
quirements of ASTM A 307.

The jointing of sections of other types of pipe shall be done in a workmanlike manner in accordance with the standard practice recommended by the pipe manufacturer.

714.13 Backfilling. The Contractor shall advise the Engineer of the time backfilling operations are expected to begin. If he is not properly advised, the Engineer may require the excavation and re-compaction of the backfill material.

The material for backfilling shall be soil that can be readily compacted. It shall not contain large stones, frozen lumps, chunks of highly plastic clay or any other material that is deemed unsuitable by the Engineer.

The backfill material shall be thoroughly compacted at the proper moisture content, in layers not exceeding 6 inches of compacted material. Compaction shall be performed by the use of mechanical tampers with the assistance of hand tampers when necessary. Care shall be exercised to thoroughly compact the backfill under the haunches of the pipe and to insure that the backfill soil is in intimate contact with the side of the pipe. The backfill shall be brought up evenly on both sides of the pipe for its full length.

Backfill compaction may be supplemented by rolling or operating heavy equipment longitudinally parallel with the culvert, provided care is taken to avoid displacement or damage of the pipe.

In addition, compaction of backfill for the corrugated high density polyethylene pipe shall be a minimum of 95% of the AASHTO T 99 maximum dry density. Care shall be given not to damage or misalign the pipe during the backfill operation.

714.14 Installing Pipe Culvert Under Existing Pavement.
On projects where the original approach pavement structure is being retained, the pipe culvert shall be laid as herein specified. The portion of the pavement structure removed due to the excavation of the trench shall be repaired using the same type of materials used in the original construction. The Engineer may accept the use of other materials as he deems appropriate. The work shall be performed as directed by the Engineer. The cost of the materials and the labor involved shall be included in the unit bid price for the culvert pipe.

714.15 Removing Existing Pipe. Existing pipe shall be removed in accordance with the provisions of Subsection 202.04.

714.16 Cleaning Out Pipe. The entire length of new and relaid pipe culverts shall be thoroughly cleaned out. Retained pipe culverts shall be maintained in the same condition as existed before beginning work.

714.17 Placing Pipe Under Railroads and Other Transportation Facilities. When the plans include the installation of pipe under railroads or other transportation facilities not under the jurisdiction of the Department, the Contractor shall, unless otherwise provided, install the pipe using such methods and procedures required by the owner. There will be no extra payment for this change in methods and procedures. This requirement will not apply to the installation under roadways.

714.18 Method of Measurement. For concrete culvert pipe, the linear feet of pipe to be measured for payment shall be the net length of each size and class or thickness of culvert pipe complete in place and accepted. The net length shall be obtained by multiplying the nominal length of the pipe sections by the number of sections used. The maximum length of pipe approved for payment shall not exceed the length required if only 4 foot sections of pipe were used.
For all culvert pipe, except concrete, the quantity of pipe to be measured for payment shall be the actual number of linear feet of each size, class, thickness, or type of culvert pipe, complete in place and accepted.

Tees, wyes, elbows, bends, reducers, and increasers shall be measured by the unit for each size, kind, and class, thickness, or type of unit, complete in place and accepted. The length of each unit will not be included in the linear feet of culvert pipe when measured as provided herein.

The excavation of unyielding, unstable, or otherwise unsuitable material necessary to obtain a satisfactory foundation for pipe culverts as outlined in Subsection 714.10, shall be measured as provided in Subsection 203.13. The unstable material shall be disposed of in the manner as outlined in Subsection 203.06.

The excavation necessary for the removal of existing pipe culverts that are not to be replaced by new culverts will be measured in cubic yards as set forth in Subsection 202.06C.

714.19 Basis of Payment. Culvert pipe, tees, wyes, bends, reducers, and increaser, measured as provided in Subsection 714.18, will be paid for at the contract unit price for the respective items, which price and payment shall be full compensation for furnishing, hauling and placing all pipe sections and materials, excavation and backfilling new or existing trench, removal of existing pipe to be replaced, constructing pipe joints, removal of old endwalls, cleaning out pipe, disposal of surplus materials and for all labor, equipment, tools and incidentals necessary to complete the work.

The excavation of unyielding or unstable material, measured as provided in Subsection 714.18, will be paid for at the contract unit price for Unclassified Excavation in accordance with Subsection 203.15.

The excavation, measured in accordance with Subsection 714.18, will be paid for at the contract unit price for Un-
classified Excavation, which price and payment shall be full compensation for all work and costs of removal, transporting, and storing or disposing of existing pipe that is not to be replaced by a new structure.

Payment for each item will include all direct and indirect costs and expenses necessary to complete the work.

Payment will be made under:

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</thead>
<tbody>
<tr>
<td>714XXXX</td>
<td>(size) (kind) Pipe Culvert Tee (class or thickness or type)</td>
<td>Each</td>
</tr>
<tr>
<td>714XXXX</td>
<td>(size) (kind) Pipe Culvert Wye (class or thickness or type)</td>
<td>Each</td>
</tr>
<tr>
<td>714XXXX</td>
<td>(size) (kind) Pipe Culvert (degree) Bend (class or thickness)</td>
<td>Each</td>
</tr>
<tr>
<td>714XXXX</td>
<td>(size) (kind) Reducer (size) to (size) Diameter (class or thickness)</td>
<td>Each</td>
</tr>
<tr>
<td>714XXXX</td>
<td>(size) (kind) Increaser (size) to (size) Diameter (class or thickness)</td>
<td>Each</td>
</tr>
</tbody>
</table>
PRINTING COST

1)  **Total Printing Cost:** $335
2)  **Total Number of Documents:** 70
3)  **Cost per Unit:** $4.78