May 21, 2010

INSTRUCTIONAL BULLETIN NO. 2010-1

SUBJECT: Culvert Pipe Structural Design Criteria
EFFECTIVE DATE: May 13, 2010
SUPERSEDES: 2007-4 “Culvert Pipe Structural Design Criteria”
RE: SCDOT Standard Drawings for permanent pipe culverts

Pipe culvert structural design procedure:

1. Use SCDOT Standard Drawing fill height tables (where applicable) that are based on calculation procedures outlined in this document.

2. When pipe installations are outside of the limits of the SCDOT Standard Drawing fill height tables, the engineer of record should provide pipe type and calculations that are site specific and meet the minimum structural design criteria outlined in this document. Use standard AASHTO/ASTM pipe geometry and configuration if appropriate. Provide a detail sheet for designed pipe indicating the standard pipe properties, installation locations, and specific installation requirements for each pipe.

3. When standard AASHTO/ASTM pipe cannot meet site requirements, consult with pipe manufacturers to confirm that a pipe is available or can be manufactured to meet the minimum structural design criteria outlined in this document for the site specific loading. Provide a structural detail sheet for each custom pipe indicating its geometry, physical properties, installation location, and custom installation requirements. For these cases, alternates such as box culverts or bridges may be appropriate.

The following parameters for the structural design of culvert pipe to be used by SCDOT for permanent installations are based on the 2007 AASHTO LRFD Bridge Design Specification, 4th Edition, the SCDOT Supplemental Technical Specification SC-M-714 (8/9), and corresponding AASHTO & ASTM material specifications. The intention of this Instructional Bulletin is to develop fill height tables for each pipe material that incorporate comprehensive design calculations in accordance with available AASHTO methodologies.

All Pipes – Submittals:

- Provide paper copies of detailed calculations signed and sealed by a Professional Engineer Licensed in the state of South Carolina
- Provide electronic copies of these detailed calculations (Excel, MathCad, or other format if previously accepted by Preconstruction Support) for each pipe configuration.
- Provide a summary fill height table showing pipe diameter and most conservative case (lowest fill height) results for each pipe gage or class in the format shown on SCDOT Standard Drawings. Provide similar tables for any non-circular pipe for future use.

All Pipes – Structural Design Criteria:

All buried pipe structures shall be designed according to the appropriate methods specified in AASHTO LRFD Bridge Design Specifications 4th Edition 2007 Section 12 (w/2009 Interim Revisions where indicated). All buried pipes must be able to resist the factored loads given by the load combinations specified in AASHTO 12.5.2 (Service Limit State) and 12.5.3 (Strength Limit State). According to the Definitions listed in AASHTO Section 1.2, the applicable Limit States are defined as follows:

- **Service Limit States** – *Limit states relating to stress, deformation, and cracking under regular operating conditions.*
- **Strength Limit States** – *Limit states relating to strength and stability during the design life.*

All Pipes – Soil/Structure Interaction:

- For bedding and backfill, use SCDOT Supplemental Specification SC-M-714, however, calculations should be based on 90% compaction of soil in bedding and structural backfill rather than 95% in order to accommodate for possible field fluctuations that proper inspections do not correct. This design level is not intended as an acceptable installation level, but only as a safety factor on proper installations as specified.
- For fill height tables – design calculations to use the most conservative soil – structure combination (that is in conformance with SCDOT specification) that yields the lowest fill height for each pipe and load case (i.e. the worst cast soil modulus that conforms with soils allowed by SC-M-714.)

All Pipes – Physical Properties:

- In each set of calculations for pipe, clearly indicate pipe physical properties including, weight (lb/ft), cross sectional area {gross & effective} (in^2), moment of inertia (in^4), radius of gyration (in), modulus of elasticity (lb/in^2), actual hydraulic area (ft^2), and Manning's roughness coefficient "n".

All Pipes – Joint Implications:

- For pipe joints (tongues & grooves, coupling bands, etc.) if structural capacity (fill height) of pipe is reduced at connection, this data should be shown in the calculations and final fill height tables or alternate connections that do not reduce capacity should be provided for inclusion on SCDOT Standard Drawings.
- For connections of pipe to drainage structures (interfaces with junction boxes, catch basins, manholes, etc.) if structural capacity (fill height) of pipe is reduced at connection, this data should be shown in the calculations and final fill height tables or alternate connections that do not reduce capacity should be provided for inclusion on SCDOT Standard Drawings.

All Pipes – Pavement:
Minimum pavement depth (used on minimum depth calculations) should be 4” graded aggregate base with 2” surface course. (Note: Does not apply to Load Case 8, listed below.)

All Pipes - Loading Criteria:
The loads used for designing all buried pipe structures shall be performed according to AASHTO 12.6. (Note: The unit weight of soil used for design calculations shall not be less than be 120 (lb/ft^3).)

Case 1: HL-93 Live Load Maximum Fill Height (Ft)
HL-93 Live Load & Soil/Road Dead Load - Design for Maximum Burial Depth to be measured from the top of pipe to the top of finished grade as dimensioned on proposed SCDOT Standard Drawings.

Case 2: HL-93 Live Load Minimum Fill Height (Ft)
HL-93 Live Load & Soil/Road Dead Load - Design for Minimum Burial Depth to be measured from the top of pipe to the top of subgrade as dimensioned on SCDOT Standard Drawings. The Minimum allowable depth of fill is determined according to AASHTO 12.6.6.3.

Case 3: 75 Kip per Axle Construction Loading Minimum Fill Height (Ft)
75 Kip Per Axle Construction Live Load & Soil Dead Load - Design for Minimum Burial Depth to be measured from the top of pipe to the top of temporary construction fill.

Case 4: New Construction Universal Driveway Zero Cover Installation – Maximum Capacity (Kip/Axle) HL-93 Live Load & Road Dead Load - Design for Surface Burial Depth where flexible or rigid pavement is installed directly on top of pipe. If HL-93 Live Load cannot be supported by pipe for this load case – Provide maximum allowable Live Load for this installation. If it is not desirable to use a particular pipe in such shallow installations, please notify us in the calculations.

Case 5: 150 Kip per Axle Construction Loading Minimum Fill Height (Not be listed on Standard Drawing) (Ft)
150 Kip Per Axle Construction Live Load & Soil Dead Load - Design for Minimum Burial Depth to be measured from the top of pipe to the top of temporary construction fill.

Case 6: HL-93 Live Load Maximum Fill Height with Hydrostatic pressure (Ft)
HL-93 Live Load, Soil/Road Dead Load, and Hydrostatic Pressure head of 2x pipe O.D. measured from the pipe invert - Design for Maximum Burial Depth to be measured from the top of pipe to the top of finished grade as dimensioned on SCDOT Standard Drawings when pipe is subjected to hydrostatic pressure.

Case 7: Pipe Handling (Not listed on Standard Drawing)
Pipe Pick Weight, Placement, Flexibility Limit, or any other construction/handling loading that requires additional pipe strength.

Case 8: Existing Residential Driveway Maintenance (Standard Drawing 714-990-MO)
This load case only applies to existing residential driveways with pipe diameters’ less than or equal to 30”, and where the depth of the ditch does not exceed 5’.

<u>Live Load for Existing Residential Driveway (Case 8)</u>
Single Dual Wheel Axial (one lane) 4 kips per dual wheel (total of 8 kips per axle). Single Dual Tandem Axial (one lane) 8 kips per axle (total of 16 kips). Effect of Lane Load can be neglected for Residential Driveway Live Load Calculations. (Direction of Vehicle Travel across/transverse to Pipe Centerline)

All Pipes – Limitations on Structural Criteria & Published Fill Height Tables:

SCDOT published fill height tables are based on internal calculations performed by the SCDOT and calculations submitted by various pipe manufactures. All calculations where performed in accordance with SCDOT Supplemental Technical Specification SC-M-714, SCDOT Standard Drawings, AASHTO LRFD Bridge Design and Material Specifications, and this Culvert Pipe Structural Design Criteria.

Since the total number of pipe installed by the SCDOT rarely exceed 30' of fill. The published SCDOT fill height tables have been limited to a maximum allowable fill height of 30' or less. SCDOT believes that fills greater than 30' warrant a custom design. This limitation on maximum fill heights will allow the design engineer to more closely examine each deep installation.

For pipe installations exceeding 30', the design engineer shall follow AASHTO Direct Design procedures regardless of the pipe type or size. The custom design may vary parameters such as reinforcement area, wall thickness, gage, or structural backfill provided that all of these parameters still meet or exceed those described in SC-M-714. For all custom designs, the engineer shall provide a structural detail sheet in the plans for each different (structural backfill, pipe size or type) deep installation, and the manufacturer shall clearly mark special designed pipe indicating it's bury depth and installation location. The structure sheet(s) provided in the plans shall include at a minimum a typical pipe cross section, installation locations, and installation requirements.

Structural Criteria for HDPE Pipe:

HDPE Materials:
HDPE Pipe in accordance with AASHTO M 294 Type S
Calculations submitted by each manufacturer since pipe geometry can vary between manufacturers.

HDPE Pipe Sizes to Evaluate (Only if available):
12, 15, 18, 24, 30, 36, 42, 48, 54, 60

HDPE Design Criteria:
AASHTO LRFD Bridge Design Specifications 4th Edition 2007 Section 12

<u>Strength Limit State</u> Design including:
Thrust
Wall Area/Resistance
Buckling (Local and Global)
Bending Strain
Combined Strain (Compressive Strain due to Thrust & Bending)
Flexibility Factor (Pipe Stiffness)

<u>Service Limit State</u> Design including:
Deflection (5% maximum)

HDPE Notes:

Each manufacturing facility wishing to provide pipe for SCDOT projects must provide calculations or certify calculations before being listed on an SCDOT Qualified Product Listing for pipe.

Structural Criteria for RC Pipe:

RCP Materials:
RCP in accordance with AASHTO M 170 Class III, Wall B & C – Worst Case
RCP in accordance with AASHTO M 170 Class IV, Wall B & C – Worst Case
RCP in accordance with AASHTO M 170 Class V, Wall B & C – Worst Case
Note: "A" wall pipe is not manufactured for SCDOT therefore calculations are not be required for "A" wall pipe.
Elliptical Reinforced Concrete in accordance with AASHTO M 207 (For Custom Designs)
*Reinforced Concrete Pipe Arch in accordance with ASTM C 506
*Note: For Custom Designs, Designer must verify the availability of Arch Pipe <u>before</u> this Option can be selected.

Concrete Compressive Strength of SCDOT Class 4000P minimum & AASHTO M170-09
All (direct & indirect design) calculations are based on wall thicknesses and reinforcement areas as listed in AASHTO M 170 except where indicated otherwise on the Standard Drawings. Steel Circumferential Reinforcement shall consist of wire conforming to AASHTO M32, M55, M221, or M225 with minimum yield strength of 65 ksi. Calculations performed by SCDOT.

RCP Sizes to Evaluate (Only if available):
12, 15, 18, 24, 30, 36, 42, 48, 54, 60, 66, 72, 78, 84, 90, 96, 108, 120
Non-circular sizes submitted by industry only if available

RCP Design Criteria:
SCDOT calculations are intended to follow AASHTO Strength Limit State (Direct Design), however, based on meetings with the RCP industry it appears that the direct design calculations for small diameter (less than 36") may have conservative phi factors for shear. In order to not penalize the concrete pipe industry, SCDOT will use indirect design calculations for small diameter pipe until such a time as AASHTO updates direct design formulas to account for the small pipe effect or clarifies the appropriate use of direct and indirect design.

AASHTO LRFD Bridge Design Specifications 4th Edition 2007 Section 12 (w/2009 Interim Revisions).

<u>**Strength Limit State**</u> Design including: (Direct Design Method used for pipe diameters equal to 36" and larger.)
Flexure
Shear (Diagonal Tension)
Thrust
Radial Tension
*Crack Width Control
*Note: Crack Width Control is evaluated at the Service Limit State

<u>**Service Limit State**</u> Design including: (Indirect Design Method used for pipe diameters equal to 30" and smaller.)
The required D-Load at which a pipe develops its ultimate strength in a three-edge bearing test is the design D-Load at a 0.01" width crack.

RCP Notes:
Each manufacturing facility wishing to provide pipe for SCDOT projects must provide calculations or certify calculations before being listed on an SCDOT Qualified Product Listing pipe.

Fill Height Table Structural Criteria for CAAP Pipe:

CAAP Materials:
CAAP in accordance with AASHTO M 196, 16 gage
CAAP in accordance with AASHTO M 196, 14 gage
CAAP in accordance with AASHTO M 196, 12 gage
CAAP in accordance with AASHTO M 196, 10 gage
CAAP in accordance with AASHTO M 196, 8 gage
CAAP pipe arch in accordance with AASHTO M 196, 16 gage
CAAP pipe arch in accordance with AASHTO M 196, 14 gage
CAAP pipe arch in accordance with AASHTO M 196, 12 gage
CAAP pipe arch in accordance with AASHTO M 196, 10 gage
CAAP pipe arch in accordance with AASHTO M 196, 8 gage
Aluminum Alloy Sheet conforming to AASHTO M 197 Alclad 3004-H32 Alloy
Calculations submitted by each manufacturer since pipe geometry can vary between manufacturers.

CAAP Sizes to Evaluate (Only if available):
2-2/3"x ½" Corrugation for 12, 15, 18, 24 Only
3"x1" Corrugation 30, 36, 42, 48, 54, 60, 66, 72, 78, 84, 90, 96, 108, 120
Non-circular sizes submitted by industry only if available

CAAP Design Criteria:
AASHTO LRFD Bridge Design Specifications 4th Edition 2007 Section 12

Strength Limit State Design including:
Thrust
Wall Area/Resistance
Buckling
Flexibility Factor
Seam resistance (if applicable)
*Deflection (5% maximum)
*Note: Not covered in AASHTO LRFD Bridge Design Specifications 4th Edition 2007

CAAP Notes:
Each manufacturing facility wishing to provide pipe for SCDOT projects must provide calculations or certify calculations before being listed on an SCDOT Qualified Product Listing for pipe.

Structural Criteria for SRAP Pipe:

SRAP Materials:
SRAP in accordance with AASHTO M 196, 16 gage
SRAP in accordance with AASHTO M 196, 14 gage
SRAP in accordance with AASHTO M 196, 12 gage
SRAP in accordance with AASHTO M 196, 10 gage
Aluminum Alloy Sheet conforming to AASHTO M 197 Alclad 3004-H32 Alloy
Calculations submitted by each manufacturer since pipe geometry can vary between manufacturers.

SRAP Sizes to Evaluate (Only if available):
12, 15, 18, 24, 30, 36, 42, 48, 54, 60, 66, 72, 78, 84, 90, 96, 108, 120

SRAP Design Criteria:
AASHTO LRFD Bridge Design Specifications 4th Edition 2007 Section 12

Strength Limit State Design including:
Thrust
Wall Area
Buckling
Flexibility Factor (Pipe Stiffness)
*Deflection (5% maximum)
*Note: Not covered in AASHTO LRFD Bridge Design Specifications 4th Edition 2007

SRAP Notes:
Each manufacturing facility wishing to provide pipe for SCDOT projects must provide calculations or certify calculations before being listed on an SCDOT Qualified Product Listing pipe.

Approved: ____
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