South Carolina
Department of Transportation

July 3, 2007

INSTRUCTIONAL BULLETIN NO. 2007-4

SUBJECT: Culvert Pipe Structural Design Criteria
EFFECTIVE DATE: June 25, 2007
SUPERSEDES: None
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 (07/08), and corresponding AASHTO & ASTM material specifications.

Our intention is to develop fill height tables for each material that incorporate comprehensive design calculations in accordance with available AASHTO methodologies.

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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 Engineering 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:

- AASHTO LRFD Bridge Design Specifications 4th Edition –
  2007 for Strength Limit State Design
  2007 for Service Limit State Design of Small Rigid Pipe (Only as indicated later)

- All pipe designs must use appropriate LRFD Section 3 and 12 dead and live load factors, resistance factors, and load modifiers to load combinations for strength limit states I, II, and IV and service limit I.

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:
Maximum pavement depth (used on maximum depth calculations) should be 24" asphalt buildup.

Minimum pavement depth (used on minimum depth calculations) should be 4" graded aggregate base with 2" surface course.

For rigid pavement calculations, provide assumed pavement thickness in calculations.

All Pipes - Loading Criteria:
Assume soil unit weight of 120 pcf for all calculations.

Case 1: HS-20 Live Load Maximum Fill Height (Ft)
HS-20 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: HS-20 Live Load Minimum Fill Height (Ft)
HS-20 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 proposed SCDOT Standard Drawings

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: Driveway Zero Cover Installation – Maximum Capacity (Kip/Axle)
HS-20 Live Load & Road Dead Load - Design for Surface Burial Depth where flexible or rigid pavement is installed directly on top of pipe.
If HS-20 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.

All Pipes - Loading Criteria:

Case 5: 150 Kip per Axle Construction Loading Minimum Fill Height (Will 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: HS-20 Live Load Maximum Fill Height with Hydrostatic pressure (Will not be listed on Standard Drawing) (Ft)
HS-20 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 proposed SCDOT Standard Drawings when pipe is subjected to hydrostatic pressure.

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

All Pipes – Limitations on Structural Criteria & Fill Height Tables to be published:

Calculations provided by each industry shall follow AASHTO calculations as described for standard installations and parameters as described in SCDOT Supplemental Technical Specification SC-M-714, SCDOT Standard Drawings, and this Culvert Pipe Structural Design Criteria.

SCDOT will publish fill height tables on pipe standard drawings in accordance with industry submitted design calculations. These fill height tables will limit Maximum Standard Installation Depths to 20'. SCDOT feels that deep installations (exceeding 20' bury) warrant custom designs, and only represent a small percentage of our total number of installations. Placing this limitation on fill heights will allow the design engineer to more closely examine each deep installation.

For these deep installations, 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.

Fill Height Table Structural Criteria for HDPE Pipe:

HDPE Materials:
HDPE Pipe in accordance with AASHTO M 294 Type S
Each manufacturer to provide calculations 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 for Strength Limit State Design

Complete Section 12.12 Strength Limit State Design, including:
Thrust
Global Buckling
Localized Buckling
Bending Strain
Combined Strain (Compressive Strain due to Thrust & Bending)
Flexibility Factor (Pipe Stiffness)
Deflection (5% maximum)

HDPE Notes:
Manufacturers in the HDPE industry may elect to develop tables that correspond to the most conservative (yielding lowest design fill height) pipe geometry. If this is done, each manufacturing facility must certify that their pipe profile meets or exceeds the data provided.

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.

Fill Height Table Structural Criteria for RC Pipe:

RCP Materials:
RCP in accordance with AASHTO M 170 Class II, Wall A, B & C – Worst Case
RCP in accordance with AASHTO M 170 Class III, Wall A, B & C – Worst Case
RCP in accordance with AASHTO M 170 Class IV, Wall A, B & C – Worst Case
RCP in accordance with AASHTO M 170 Class V, Wall A, B & C – Worst Case
Elliptical Reinforced Concrete in accordance with AASHTO M 207 (optional)
Reinforced Concrete Pipe Arch in accordance with ASTM C 506 (optional)

Yield strength of circumferential reinforcement ASTM A 706 grade 60
Concrete Compressive Strength of SCDOT Class 4000P minimum & AASHTO M 170
Nonstandard shear reinforcement should not be considered for these calculations.
All (direct & indirect design) calculations provided should be based on wall thicknesses and reinforcement areas as they are listed in AASHTO M 170-05.

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:
Based on meetings with the pipe industries, it appears that the AASHTO formulas for direct design of small diameter rigid pipe may have conservative phi factors for shear. We ask that the concrete industry provide calculations in accordance to AASHTO direct design for ALL pipe sizes for our files. Additionally, we ask that the industry provide AASHTO direct design calculations with modified shear phi factors for pipes less than 36" diameter for comparison to indirect design and D-load testing. And finally, we ask the industry to provide AASHTO indirect design calculations to support the D-load testing for pipes less than 36" diameter.

AASHTO LRFD Bridge Design Specifications 4th Edition –
2007 for Strength Limit State Design (Provide for ALL Pipe Sizes)
Complete Section 12.10 Strength Limit State Design (Direct Design), including:
Crack Control, Flexure, Thrust, Shear, Diagonal Tension, & Radial Tension

AASHTO LRFD Bridge Design Specifications 4th Edition –
2007 for Service Limit State Design (for 12, 15, 18, 24, & 30 inch diameter pipes only)
Complete Section 12.10 Service Limit State Design (Indirect Design) for the 0.01 in crack, including: Flexure, Thrust, Shear, & Radial Tension

RCP Notes:
We will note on the standard drawings that special designed pipe (including additional shear reinforcement) may be designed if required on a case by case basis, but these configurations should not be included in the Standard Drawing design submittal. We will also indicate that fill heights are based on indirect design for pipes smaller than 36" dia, and direct design for 36" dia and larger.

Manufacturers in the RCP industry may elect to develop tables as an industry. If this is done, each manufacturing facility must certify that their pipe design meets or exceeds the data provided.

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

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 for Strength Limit State Design

Complete Section 12.7 Strength Limit State Design, including:
Thrust
Wall Area
Buckling
Flexibility Factor
Seam resistance (if applicable)
Deflection (5% maximum)

CAAP Notes:
Manufacturers in the CAAP industry may elect to develop tables as an industry. If this is done, each manufacturing facility must certify that their pipe design meets or exceeds the data provided.

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.

Fill Height Table 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

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 for Strength Limit State Design

Complete Section 12.7 Strength Limit State Design, including:
Thrust
Wall Area
Buckling
Flexibility Factor (Pipe Stiffness)
Deflection (5% maximum)

SRAP Notes:

Manufacturers in the SRAP industry may elect to develop tables as an industry. If this is done, each manufacturing facility must certify that their pipe design meets or exceeds the data provided.

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: _____

E. S. Eargle
Preconstruction Support Engineer

ESE:hjc
cc:
Danny Shealy, Director of Construction
Jim Feda, Director of Maintenance
Charles Smoak, Hydraulic Design Engineer
Milt Fletcher, Material and Research Engineer
Jim Frick, Letting Preparation Manager
Rob Bedenbaugh, Roadway Engineer Manager
Thad Kitowicz, FHWA
Matt Lifsey, RP Engineer - Lowcountry
Mitchell Metts, RP Engineer - Pee Dee
Randall Young, RP Engineer - Midlands
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File:PC/ESE