NCDOT PIPE LINER MANUAL

HYDRAULICS UNIT v. 2019 07 15

NCDOT PIPE LINER MANUAL

I. PURPOSE

This manual describes the design methodologies required by the NCDOT for rehabilitation of existing storm water pipes or culverts by lining methods.

Pipe liner systems used for rehabilitation shall be from the NCDOT Approved Products List and may be subject to limitations for use as specified herein, by site-specific limitations, limitations imposed by the Engineer, or limitations as shown on the NCDOT Approved Products List for the specific liner system. The designer shall consult the Department to determine the method or methods that are to be considered at each rehabilitation location.

The design calculations shall support the acceptability of the proposed rehabilitation system to provide the necessary hydraulic capacity and structural strength to support the anticipated total load and hydrology at the site of rehabilitation, as determined from a review that has been signed and sealed by a Professional Engineer holding a valid license to practice engineering in the State of North Carolina (unless an exception is noted below). Such certification shall cover all design data, supporting calculations, installation plan, and planned rehabilitation materials. The calculations shall indicate that the liner design is for a full structural replacement of a fully deteriorated host pipe.

II. DESIGN METHODS

Category A - Cured-In-Place Pipe (CIPP) liners are lining an existing culvert by either pulling or inverting a resin-impregnated fabric tube and curing the tube in place. When CIPP liners are specified, the liner system shall conform to the following requirements as supported by submitted design calculations:

- Must provide hydraulic calculations comparing existing culvert to proposed culvert liner.
- Must provide structural calculations.
- CIPP liner thicknesses conforming to *NCDOT Cured In Place Pipe (CIPP) Liner Thickness Selection Guide* may be installed without submitting structural design calculations as long as the assumptions therein are met.

- Standards references:
  - ASTM D5813
  - ASTM F1216 for inverted CIPP
  - ASTM F1743 for pulled-in-place CIPP
  - ASTM F2019 for pulled-in-place GRP CIPP
  - ASTM F2599 for sectional inverted CIPP (applies to pipe sections, not full length)

- Must exactly follow ASTM F1216 Appendix X1.2.2 Fully Deteriorated Gravity Pipe Conditions, and check as follows:

  - Liner thickness to be greatest of: partially deteriorated Eqn. X1.1, partially deteriorated Eqn. X1.2, partially deteriorated Max. SDR (DR) of 100 Note X1.2, fully deteriorated Eqn. X1.3, and fully deteriorated minimum thickness check Eqn. X1.4. Per ASTM F1216 X1.2.2.2.

- Minimum pipe ovality of 2% used for calculations.

  - If actual ovality is greater than 10% as described in ASTM F1216 X1.1.1, submit calculations based on alternative design methods per ASTM F1216 X1.1.1.

- Soil Enhancement Factor, maximum of 7.

- Poisson's Ratio = 0.3.

- Grout is assumed to have no greater load bearing capacity than surrounding soil.

- Assume groundwater table elevation at greater of: crown of pipe or ½ the distance between lowest invert of pipe and highest ground elevation over pipe.

- Traffic loading is HS-20. Neglect after 8 ft of cover on single barrel culverts if span length is 8 ft or less. For multiple span culverts, the effects may be neglected where the depth of fill exceeds the distance between inside faces of endwalls. See AASHTO LRFD Bridge Design Specifications for additional information.

- Total unit weight of soil is 120 pcf.

- Modulus of soil reaction is 1000psi.

- Factor of safety N = 2.0.

- Long Term Modulus of Elasticity for calculations = 150,000 psi. NCDOT Type 2 or Type 5 certifications may be submitted by vendors or contractors for proof of alternate Long Term Modulus of Elasticity extrapolated from ASTM D2990, 10000-hour test. Design value of Long Term Modulus of Elasticity may be no greater than 50% of Initial Modulus of Elasticity. Tested value must be greater than or equal to value used in design equations.

- Initial Modulus of Elasticity for calculations = 300,000 psi. NCDOT Type 2 or Type 5 certifications may be submitted by vendors or contractors for proof of alternate Initial Modulus of Elasticity based on ASTM D790. Tested value must be greater than or equal to value used in design equations.

- Long Term Flexural Strength = 2250 psi. NCDOT Type 2 or Type 5 certifications may be submitted by vendors or contractors for proof of alternate Long Term Flexural Strength extrapolated from ASTM D2990, 10000-hour test. Tested value must be greater than or equal to value used in design equations.

NCDOT Cured In Place Pipe (CIPP) Liner Thickness Selection Guide

CURED IN PLACE PIPE (CIPP)
FULLY DETERIORATED HOST PIPE
H20 LOADING ASSUMED
BASED ON ASTM F1216 DESIGN METHODS

7	= Soil Enhancement Factor
150000psi	= Long Term Modulus of Elasticity
2250psi	= Long Term Flexural Strength
300000psi	= Initial Modulus of Elasticity
1000psi	= Modulus of Soil Reaction
10%	= Ovality
0.3	= Poisson's Ratio
120pcf	= Unit weight of soil
2	= Factor of Safety

INSIDE DIAMETER OF HOST PIPE (IN)	FILL HEIGHT OVER TOP OF PIPE (FT) >>>	1	2	3	10	16	20	26	30	35	40	50
12	LINER THICKNESS (IN) >>>	0.33	0.22	0.21	0.23	0.29	0.33	0.36	0.39	0.42	0.44	0.49
15	LINER THICKNESS (IN) >>>	0.41	0.28	0.26	0.29	0.37	0.41	0.46	0.48	0.52	0.55	0.62
18	LINER THICKNESS (IN) >>>	0.49	0.33	0.31	0.35	0.44	0.49	0.55	0.58	0.62	0.66	0.74
24	LINER THICKNESS (IN) >>>	0.66	0.43	0.41	0.46	0.58	0.65	0.73	0.77	0.83	0.88	0.98
30	LINER THICKNESS (IN) >>>	0.82	0.54	0.51	0.58	0.73	0.81	0.91	0.96	1.03	1.10	1.23
36	LINER THICKNESS (IN) >>>	0.99	0.64	0.60	0.71	0.87	0.96	1.08	1.15	1.24	1.32	1.47
42	LINER THICKNESS (IN) >>>	1.15	0.75	0.70	0.84	1.01	1.12	1.26	1.34	1.44	1.53	1.72
48	LINER THICKNESS (IN) >>>	1.31	0.86	0.80	0.98	1.16	1.28	1.44	1.53	1.64	1.75	1.96
54	LINER THICKNESS (IN) >>>	1.48	0.97	0.90	1.12	1.32	1.44	1.61	1.72	1.85	1.97	2.20
60	LINER THICKNESS (IN) >>>	1.64	1.07	1.04	1.26	1.48	1.61	1.79	1.91	2.05	2.18	2.44
66	LINER THICKNESS (IN) >>>	1.81	1.20	1.20	1.41	1.65	1.79	1.98	2.10	2.25	2.40	2.68
72	LINER THICKNESS (IN) >>>	1.97	1.36	1.36	1.56	1.82	1.97	2.18	2.30	2.45	2.61	2.92
78	LINER THICKNESS (IN) >>>	2.14	1.53	1.53	1.72	1.99	2.16	2.38	2.51	2.67	2.82	3.16
84	LINER THICKNESS (IN) >>>	2.30	1.71	1.71	1.88	2.17	2.34	2.58	2.72	2.89	3.04	3.40

Assumed groundwater table elevation at greater of: crown of pipe or ½ the distance between lowest invert of pipe and highest ground elevation over pipe.

Do not use this table for pipes with greater than 10% Ovality.

Δ = percentage ovality of original pipe equals

$$100 \times \frac{(\textit{Mean Inside Diameter} - \textit{Minimum Inside Diameter})}{\textit{Mean Inside Diameter}}$$

or

$$100 \times \frac{(\textit{Maximum Inside Diameter} - \textit{Mean Inside Diameter})}{\textit{Mean Inside Diameter}}$$

When **Category B Fold and Form flexible liners** are specified, the liner system shall conform to the following requirements as supported by submitted design calculations:

- Must provide hydraulic calculations comparing existing culvert to proposed culvert liner.
- Must provide structural calculations.
- Standards references:
    - ASTM D1784 defines PVC cell class referenced below
    - ASTM F1504 for PVC cell classification 12334 or 13223
    - ASTM F1533 for polyethylene
    - ASTM F714 for polyethylene min. cell classification 335420 and 2-4% carbon black
    - ASTM F1606 for deformed polyethylene
    - ASTM F1947 for folded PVC
- Methods & pipe classification not permitted for use due to low pipe strength:
    - ASTM F1867 for folded / formed PVC Type A
    - ASTM F1871 for PVC Type A cell classification 12111

- Polyethylene liner may not be used in applications where liner creep due to thermal expansion and contraction will be a detriment, such as a pipe with direct lateral connections.

- Minimum SDR shall be 32.5 to limit liner thickness and ensure adequate liner material properties.

- Must exactly follow ASTM F1606 Appendix X1.2.2 Fully Deteriorated Design Condition for Polyethylene; or ASTM F1947 Appendix X1.2.2 Fully Deteriorated Design Condition for PVC.

    - Check Fully Deteriorated design thickness against ASTM F1606 Appendix X1.2.1 Partially Deteriorated design thickness for Polyethylene; and ASTM F1947 Appendix X1.2.1 Partially Deteriorated design thickness for PVC. Use the thicker of Partially Deteriorated and Fully Deteriorated design methods.

- Minimum pipe ovality of 2% used for calculations.

    - If actual ovality is greater than 12.5% as described in ASTM F1947, submit calculations based on alternative design methods.

- Soil Enhancement Factor, maximum of 7.

- Poisson's Ratio = 0.45 for PE and 0.38 for PVC.

- Grout is assumed to have no greater load bearing capacity than surrounding soil.

- Assume groundwater table elevation at greater of: crown of pipe or ½ the distance between lowest invert of pipe and highest ground elevation over pipe.

- Traffic loading is HS-20. Neglect after 8 ft of cover on single barrel culverts if span length is 8 ft or less. For multiple span culverts, the effects may be neglected where the depth of fill exceeds the distance between inside faces of endwalls. See AASHTO LRFD Bridge Design Specifications for additional information.

- Total unit weight of soil is 120 pcf.

- Modulus of soil reaction is 1000psi.

- Factor of safety N = 2.0.

- Long Term Modulus of Elasticity, 50-year sustained loading value shall be used. 22,000 psi shall be used for HDPE, PE, PP; and 140,000 psi shall be used for PVC; per AASHTO LRFD Bridge Design Specifications 8^{th} ed., Table 12.12.3.3-1. Alternately, NCDOT Type 2 or Type 5 certifications may be submitted by vendors or contractors for proof of value used in calculations.

When **Category C HDPE, PE, PVC, PP, solid wall slip liners** are specified, the liner system shall conform to the following requirements as supported by submitted design calculations:

- Must provide hydraulic calculations comparing existing culvert to proposed culvert liner.
- Must provide structural calculations.
- Solid Wall HDPE, PE, and PP (Not PVC) Liners conforming to *NCDOT Solid Wall Polyethylene or Polypropylene Pipe Liner Allowable Fill Height Table* may be installed without submitting structural design calculations as long as the assumptions therein are met.

- Must be closed profile; i.e. no definable bell and spigot that protrudes from the outer wall of the pipe.

- Structural design must follow AASHTO LRFD Bridge Design Specifications, Section 12, for thermoplastic pipe. Unless specified below, the 4^{th} edition and newer can be used. Provide calculations evaluating the following failure mechanisms for Long Term (50-year) loading conditions:

    - Wall Thrust
    - Deflection
    - Buckling (and Local Buckling for Corrugated Pipe only)
    - Compression Strain
    - Bending Strain / Flexural Strain
    - Combined Strain

- Manufacturer Literature must provide:
    - Inside Diameter
    - Outside Diameter
    - Pipe Stiffness (pii)
    - Wall Gross Section Area (in^2/in)
    - Wall Effective Area (in^2/in) (for corrugated / profile pipe only)
    - Distance to Centroid (c) (in)
    - Moment of Inertia (I) (in^4/in)

- Standards references:
    - ASTM D1784 defines PVC cell class referenced below
    - ASTM D3350 defines PE cell class referenced below
    - ASTM F714 for solid wall polyethylene min cell classification 345464 and 2–4% carbon black
    - AASHTO M326 for solid wall polyethylene
    - ASTM D3034 for solid wall PVC, min. cell classification 12454

- ASTM F679 for solid wall PVC, large diameter, min. cell classification 12454
- ASTM D2241 for solid wall PVC, min. cell classification 12454
- ASTM F585 for polyethylene slip-line
- ASTM F2620 for polyethylene heat fusion joining

- Traffic loading is HS-20. Neglect after 8 ft of cover on single barrel culverts if span length is 8 ft or less. For multiple span culverts, the effects may be neglected where the depth of fill exceeds the distance between inside faces of endwalls. See AASHTO LRFD Bridge Design Specifications for additional information.

- Grout is assumed to have no greater load bearing capacity than surrounding soil.

- Total unit weight of soil is 120 pcf.

- Φs = 0.9, Resistance Factor for Soil Stiffness, AASHTO LRFD Bridge Design Specifications 8th ed. Table 12.5.5-1.

- ήLL = 1, Live Load load Modifier, AASHTO LRFD Bridge Design Specifications 8th ed. Article 1.3.2

- γLL = 1, Live Load Factor, Service I, AASHTO LRFD Bridge Design Specifications 8th ed. Table 3.4.1-1

- Use Sandy Soil, 85% compaction, for determination of Secant Constrained Soil Modulus (Ms), from AASHTO LRFD Bridge Design Specifications 8th ed. Table 12.12.3.5-1.

- ήEV = 1.05, Load Modifier, AASHTO LRFD Bridge Design Specifications 8th ed. Article 1.3.2

- γEV = 1.425, Dead Load Factor, AASHTO LRFD Bridge Design Specifications 8th ed. Table 3.4.1-2

- γWA = 1, Hydrostatic Load Factor, AASHTO LRFD Bridge Design Specifications 8th ed. Table 3.4.1-1

- KγE = 1.5, Installation Factor, AASHTO LRFD Bridge Design Specifications 8th ed. Article 12.12.3.5

- D_L = 1.5, Deflection Lag Factor, AASHTO LRFD Bridge Design Specifications 8th ed. Article 12.12.2.2

- K_B = 0.1, Bedding Coefficient, AASHTO LRFD Bridge Design Specifications 8th ed. Article 12.12.2.2

- Fu = 1440psi for HDPE, PE, PP and 2600psi for PVC. Tensile Strength 50-year sustained loading value. AASHTO LRFD Bridge Design Specifications 8th ed. Table 12.12.3.3-1

- ϕt = 1, Resistance Factor for Thrust, AASHTO LRFD Bridge Design Specifications 8th ed. Table 12.5.5-1

- Use Dumped Gravel backfill condition for determination of Shape Factor, Df. AASHTO LRFD Bridge Design Specifications 8th ed. Table 12.12.3.10.2b-1.

- Long Term Modulus of Elasticity, 50-year sustained loading value shall be used. 22,000 psi shall be used for HDPE, PE, PP; and 140,000 psi shall be used for PVC; per AASHTO LRFD Bridge Design Specifications 8th ed., Table 12.12.3.3-1. Alternately, contractor or vendor may provide NCDOT Type 2 or Type 5 certifications for proof of value used in calculations.

- Short Term Modulus of Elasticity (used to compute Pipe Stiffness (PS) (pii) if not provided by Manufacturer) shall be 110,000 psi for HDPE, PE, PP; and 440,000 psi for PVC. AASHTO LRFD Bridge Design Specifications 8th ed. Table 12.12.3.3-1

- The liner pipe must carry one hundred (100) percent of the design load without taking into account the strength of the host pipe.

- Maximum deflection shall be 5 percent for PE, and either 5 percent or 3.5 percent for PVC depending on cell class as per AASHTO LRFD Bridge Design Specs 8th ed. Table 12.12.3.3-1, and 3.5 percent for PP.

- Assume groundwater table elevation at greater of: crown of pipe or ½ the distance between lowest invert of pipe and highest ground elevation over pipe.

- Manning's N number for open channel flow n = 0.011 for smooth interior PVC and 0.012 for smooth interior HDPE and PP. (For hydraulic design.)

NCDOT SOLID WALL POLYETHYLENE OR POLYPROPYLENE PIPE LINER ALLOWABLE FILL HEIGHT TABLE

FULLY DETERIORATED HOST PIPE
H20 LOADING ASSUMED
BASED ON AASHTO LRFD SECTION 12 DESIGN METHODS
DIMENSIONS BASED ON PIPE OF SDR 32.5. NOT FOR USE WITH OTHER PIPE DIMENSIONS.
NOT FOR USE WITH PVC

OUTSIDE DIAMETER OF LINER PIPE (IN)	INSIDE DIAMETER OF LINER PIPE (IN)	MINIMUM FILL HEIGHT (FT) TO SUPPORT H20 LIVE LOAD	MAXIMUM FILL HEIGHT (FT)
12.75	12.0	2	10
14	13.1	2	10
16	15.0	2	10
18	16.9	2	10
20	18.8	2	10
22	20.6	2	10
24	22.5	2	10
28	26.3	2	10
30	28.2	2	10
32	30.0	2	10
36	33.7	2	10
42	39.4	1	10
48	45.1	1	10
54	50.7	1	10
63	59.1	1	10

0% Ovality of Liner Assumed
22000psi = Long Term Modulus of Elasticity
120pcf = Unit Weight of Soil
Sandy Soil @ 85% compaction assumed in AASHTO Table 12.12.3.5-1
Pipe Stiffness Assumed to be 16 pii
Df, Shape Factor assumed to be 5.2 for dumped gravel @ < 85% compaction
1440psi = Fu, Long Term Tensile Strength
0.041 in/in = Compression Strain Limit
5% = Allowable Deflection

When **Category D HDPE, PVC, PP corrugated, profile wall, steel reinforced, or spiral wound slip liners** are specified, the liner system shall conform to the following requirements as supported by submitted design calculations:

- Must provide hydraulic calculations comparing existing culvert to proposed culvert liner.
- Must provide structural calculations.
- Standards references:
    - ASTM D1784 defines PVC cell class referenced below
    - AASHTO M294 for polyethylene profile wall (See NCDOT Standard Specifications 1032-7)
    - ASTM F894 for profile polyethylene
    - ASTM F2562 or F2435 for steel reinforced polyethylene min. cell classification 334452 and 2-4% carbon black
    - AASHTO M304 for profile PVC (see NCDOT Standard Specifications 1032-8)
    - ASTM F1803 for closed profile PVC
    - ASTM F949 and F794 for corrugated PVC min cell classification 12454
    - AASHTO M330 for corrugated polypropylene
    - AASHTO MP20-13 for steel reinforced polyethylene ribbed
    - ASTM F1735 PVC for profile strip / spiral wound, min. cell classification 12454
        - Steel Reinforced – Resin conforms to ASTM D3350, min. cell classification 335420 and 2-4% carbon black. Steel fully encapsulated.
    - ASTM F1697 PVC for profile strip / machine spiral wound, min. cell classification 13354 (for Type A) or 12344 (for Type B) or higher, as defined in Specification D1784.
        - Steel Reinforced – Resin conforms to ASTM D3350, min. cell classification 335420 and 2-4% carbon black. Steel fully encapsulated.
    - ASTM F585 for polyethylene slip-line
    - ASTM F1698 for PVC spiral wound
    - ASTM F1741 for PVC machine spiral wound

- Structural Design Methods:
    - Pipe conforming to NCDOT Standard Specifications 1032-7 & 1032-8 (AASHTO M294 & M304) may be installed without structural design computations if done so in accordance with the NCDOT Pipe Material Selection Guide fill height tables.
    - Spirally wound liners will follow Fully Deteriorated conditions of ASTM F1698 or F1741 as appropriate:
        - Check Required Fully Deteriorated design Moment of Inertia (I) of unassembled Liner Strip against Partially Deteriorated Moment of Inertia (I). Use the greater Required Moment of Inertia generated by Partially Deteriorated and Fully Deteriorated design methods.
        - Minimum pipe ovality of 2% used for calculations.
            - If actual ovality is greater than 10%, follow ASTM F1741 X1.3.
        - Factor of Safety, N = 2
        - Moment of Inertia, I, of unassembled Liner Strip proposed shall either:
            - Be provided by the manufacturer literature.

- Or, conform to closest match with ASTM F1741 Table 1 or Table 2 (as appropriate for liner type) for both hand and machine wound liners.

- Poisson's Ratio = 0.38 for PVC-only. 0.29 for steel reinforced PVC profiles
- Enhancement Factor, maximum of 7.
- Ungrouted Arc Factor = 25

- Otherwise, Structural design must follow AASHTO LRFD Bridge Design Specifications, Section 12, for thermoplastic pipe. Unless specified below, the 4th edition and newer can be used. Provide calculations evaluating the following failure mechanisms for Long Term (50-year) loading conditions:

  - Wall Thrust
  - Deflection
  - Buckling (and Local Buckling for Corrugated Pipe only)
  - Compression Strain
  - Bending Strain / Flexural Strain
  - Combined Strain

- o Φs = 0.9, Resistance Factor for Soil Stiffness, AASHTO LRFD Bridge Design Specifications 8th ed. Table 12.5.5-1.

- o ήLL = 1, Live Load load Modifier, AASHTO LRFD Bridge Design Specifications 8th ed. Article 1.3.2

- o γLL = 1, Live Load Factor, Service I, AASHTO LRFD Bridge Design Specifications 8th ed. Table 3.4.1-1

- o Use Sandy Soil, 85% compaction, for determination of Secant Constrained Soil Modulus (Ms), from AASHTO LRFD Bridge Design Specifications 8th ed. Table 12.12.3.5-1.

- o ήEV = 1.05, Load Modifier, AASHTO LRFD Bridge Design Specifications 8th ed. Article 1.3.2

- o γEV = 1.425, Dead Load Factor, AASHTO LRFD Bridge Design Specifications 8th ed. Table 3.4.1-2

- o γWA = 1, Hydrostatic Load Factor, AASHTO LRFD Bridge Design Specifications 8th ed. Table 3.4.1-1

- o KγE = 1.5, Installation Factor, AASHTO LRFD Bridge Design Specifications 8th ed. Article 12.12.3.5

- o D_L = 1.5, Deflection Lag Factor, AASHTO LRFD Bridge Design Specifications 8th ed. Article 12.12.2.2

- o K_B = 0.1, Bedding Coefficient, AASHTO LRFD Bridge Design Specifications 8th ed. Article 12.12.2.2

- o Fu = 1440psi for HDPE, PE, PP and 2600psi for PVC. Tensile Strength 50-year sustained loading value. AASHTO LRFD Bridge Design Specifications 8^{th} ed. Table 12.12.3.3-1

- o ϕt = 1, Resistance Factor for Thrust, AASHTO LRFD Bridge Design Specifications 8^{th} ed. Table 12.5.5-1

- o Use Dumped Gravel backfill condition for determination of Shape Factor, Df. AASHTO LRFD Bridge Design Specifications 8^{th} ed. Table 12.12.3.10.2b-1.

- o Short Term Modulus of Elasticity (used to compute Pipe Stiffness (PS) (pii) if not provided by Manufacturer) shall be 110,000 psi for HDPE, PE, PP (AASHTO LRFD Bridge Design Specifications 8^{th} ed. Table 12.12.3.3-1) and 400,000 psi for PVC (ASTM D1784 for above cell classification).

- Manufacturer Literature must provide:
    - o Inside Diameter
    - o Outside Diameter
    - o Pipe Stiffness (pii)
    - o Wall Gross Section Area (in^2/in)
    - o Wall Effective Area (in^2/in) (for corrugated / profile pipe only)
    - o Distance to Centroid (c) (in)
    - o Moment of Inertia (I) (in^4/in)

- Assume groundwater table elevation at greater of: crown of pipe or ½ the distance between lowest invert of pipe and highest ground elevation over pipe.

- Traffic loading is HS-20. Neglect after 8 ft of cover on single barrel culverts if span length is 8 ft or less. For multiple span culverts, the effects may be neglected where the depth of fill exceeds the distance between inside faces of endwalls. See AASHTO LRFD Bridge Design Specifications for additional information.

- Grout is assumed to have no greater load bearing capacity than surrounding soil.

- Total unit weight of soil is 120 pcf.

- Modulus of soil reaction is 1000 psi.

- Long Term Modulus of Elasticity, 50-year sustained loading value shall be used. 22,000 psi shall be used for HDPE, PE, PP; and 140,000 psi shall be used for PVC; per AASHTO LRFD Bridge Design Specifications 8^{th} ed., Table 12.12.3.3-1. Alternately, contractor or vendor may provide NCDOT Type 2 or Type 5 certifications for proof of value used in calculations.

- The liner pipe must carry one hundred (100) percent of the design load without taking into account the strength of the host pipe.

- Maximum deflection, deflection needed in any computations, and service long-term tension strain limit shall be 5 percent for PE, and either 5 percent or 3.5 percent for PVC depending on cell class as per AASHTO LRFD Bridge Design Specs 8^{th} ed. Table 12.12.3.3.1, and 3.5 percent for PP. (Percent of inside diameter of pipe.)

- Manning's N number for open channel flow n = 0.011 for smooth interior PVC and 0.012 for smooth interior HDPE and PP. (For hydraulic design.)

Category E - Spray-on liners consist of conduit lining with spray applied, factory blended cementitious, geopolymer, or other material. The liner system shall conform to the following requirements as supported by submitted design calculations:

- Must provide hydraulic calculations comparing existing culvert to proposed culvert liner.
- Must provide structural calculations.
- Must provide proof of initial Manning's Number (n value for roughness in open channel flow) of product.
- Must list liner material type.
- Must list typical, minimum, maximum application thicknesses.
- Must provide volume (cubic yards or cubic feet) of liner material planned for use in each host pipe for comparison to quantity used during construction. For example, cubic yards of dry, unmixed cementitious liner material.

- The liner pipe must carry one hundred (100) percent of the design load without taking into account the strength of the host pipe.

- Traffic loading is HS-20. Neglect after 8 ft of cover on single barrel culverts if span length is 8 ft or less. For multiple span culverts, the effects may be neglected where the depth of fill exceeds the distance between inside faces of endwalls. See AASHTO LRFD Bridge Design Specifications for additional information.

- Minimum thickness for cementitious or geopolymer liner material is 1 inch (clear of corrugations and / or bolt heads).

- Host pipe grouting is assumed to have no greater load bearing capacity than surrounding soil.

- In addition to structural calculations as required by this manual, a contractor or vendor may submit structural design calculations that use proprietary methods for comparison by NCDOT. NCDOT is under no obligation to accept proprietary design methods. The proprietary method equations may use a partially deteriorated or fully deteriorated condition. The optional proprietary design (if assuming partially deteriorated) shall incorporate a condition assessment of the current state of the stresses in the existing soil-pipe structure interaction system; producing the required minimum thickness of the proposed lining material to perform its structural role in the new liner-soil-pipe structure interaction system. Include the proposed lining material's physical properties used in the design calculations and the controlling performance parameters. Include whether the liner relies on bonding to the host pipe to achieve structural design capacity.

- One of the following two design options shall be used depending on whether the liner exhibits Rigid Pipe or Flexible Pipe behavior:

  - Liners which exhibit Rigid Pipe behavior, such as <u>Cementitious or geopolymer liners, shall be treated as non-reinforced concrete pipe</u>. Rigid Pipe behavior is characterized by cracking when subjected to 2% or greater deflection.

- Follow AASHTO LRFD Bridge Design Specifications 8th ed., Section 12.10, Indirect Design Method; to determine required Design (D) Load to be imposed on liner.

- Vendor or contractor must provide allowable D-Load of proposed liner assuming fully deteriorated host pipe condition in accordance with ASTM C497 three edge bearing test for non-reinforced pipe. (To be verified with NCDOT Type 2 or Type 5 certifications during construction.)

  - The D-Load documentation submitted must be for test specimens that are less than or equal to the proposed liner thickness, equal to host pipe inside diameter and shape, and greater than or equal to host pipe ovality in the case of a deformed host pipe.

  - If manufacturer's ASTM C497 test is conducted on a smooth wall host form (such as a cardboard or plastic sonotube), and the proposed liner is to be installed in a host pipe with internal corrugations or bolt heads, only the liner thickness clear of the corrugations or bolt heads may be considered as structural.

- Traffic loading is HS-20. Neglect after 8 ft of cover on single barrel culverts if span length is 8 ft or less. For multiple span culverts, the effects may be neglected where the depth of fill exceeds the distance between inside faces of endwalls. See AASHTO LRFD Bridge Design Specifications for additional information.

- Assume Type 1 installation for AASHTO LRFD required D-Load determination.

- Use installation factor of 1.1 in required D-Load determination.

- Unit weight of soil is 120 pcf.

o Liners which exhibit Flexible Pipe behavior (can withstand greater than 2% deflection without structural damage) shall be designed as Thermoplastic Pipe. Cementitious and geopolymer liners are not eligible for this method:

- Structural design must follow AASHTO LRFD Bridge Design Specifications, Section 12, for thermoplastic pipe. Unless specified below, the 4th edition and newer can be used. Provide calculations evaluating the following failure mechanisms for Long Term (50-year) loading conditions:

  - Wall Thrust
  - Deflection
  - Buckling (and Local Buckling for Corrugated Pipe only)
  - Compression Strain
  - Bending Strain / Flexural Strain
  - Combined Strain

- Manufacturer Literature must provide:
  - Inside Diameter
  - Outside Diameter
  - Pipe Stiffness (pii)
  - Wall Gross Section Area (in^2/in)
  - Wall Effective Area (in^2/in) (for corrugated / profile pipe only)
  - Distance to Centroid (c) (in)
  - Moment of Inertia (I) (in^4/in)

- Φs = 0.9, Resistance Factor for Soil Stiffness, AASHTO LRFD Bridge Design Specifications 8th ed. Table 12.5.5-1.

- ήLL = 1, Live Load load Modifier, AASHTO LRFD Bridge Design Specifications 8th ed. Article 1.3.2

- γLL = 1, Live Load Factor, Service I, AASHTO LRFD Bridge Design Specifications 8th ed. Table 3.4.1-1

- Use Sandy Soil, 85% compaction, for determination of Secant Constrained Soil Modulus (Ms), from AASHTO LRFD Bridge Design Specifications 8th ed. Table 12.12.3.5-1.

- ήEV = 1.05, Load Modifier, AASHTO LRFD Bridge Design Specifications 8th ed. Article 1.3.2

- γEV = 1.425, Dead Load Factor, AASHTO LRFD Bridge Design Specifications 8th ed. Table 3.4.1-2

- γWA = 1, Hydrostatic Load Factor, AASHTO LRFD Bridge Design Specifications 8th ed. Table 3.4.1-1

- KγE = 1.5, Installation Factor, AASHTO LRFD Bridge Design Specifications 8th ed. Article 12.12.3.5

- D_L = 1.5, Deflection Lag Factor, AASHTO LRFD Bridge Design Specifications 8th ed. Article 12.12.2.2

- K_B = 0.1, Bedding Coefficient, AASHTO LRFD Bridge Design Specifications 8th ed. Article 12.12.2.2

- ϕt = 1, Resistance Factor for Thrust, AASHTO LRFD Bridge Design Specifications 8th ed. Table 12.5.5-1

- Use Dumped Gravel backfill condition for determination of Shape Factor, Df. AASHTO LRFD Bridge Design Specifications 8th ed. Table 12.12.3.10.2b-1.

- Assume groundwater table elevation at greater of: crown of pipe or ½ the distance between lowest invert of pipe and highest ground elevation over pipe.

- Total unit weight of soil is 120 pcf.

- Modulus of soil reaction is 1000 psi.

- Long Term Modulus of Elasticity, 50-year sustained loading value shall be used. Vendor or contractor must provide value used in calculations. It shall be estimated by using 50% of the Initial Modulus of Elasticity value provided by ASTM D790. (To be verified with NCDOT Type 2 or Type 5 certifications during construction.)

- Tensile Strength 50-year sustained loading value (Fu) shall be used. Vendor or contractor must provide value used in calculations. It shall be estimated by using 50% of the Initial Tensile Strength value provided by ASTM D638. (To be verified with NCDOT Type 2 or Type 5 certifications during construction.)

- Maximum deflection, deflection needed in any computations, and service long-term tension strain limit shall be lesser of 5% and manufacturer recommendation.

Category F - Smooth-wall steel pipe liner rehabilitation materials shall conform to Section 1032-5 of the Standard Specifications, except as altered herein.

Grade B pipe shall be used with minimum wall thicknesses as follows:

Nominal Size (inches)	Minimum Wall Thickness (inches)
24	0.5
30	0.5
36	0.5
42	0.625
48	0.625
54	0.75
60	0.875
66	0.875
72	1.0