Spray Applied Non-Structural Pipe Liners
Technical Committee Meeting Agenda
Working Session #10

Wednesday, May 11, 2016 10:30AM – 12:00PM

Please sign the attendance sheet

1) 10:30AM-10:40AM: Call to Order and Introductions

2) 10:40AM-10:55AM: Update-Program Status
   Structural Section Addition – Jeff Syar
   Office of Hydraulic Engineering at ODOT
   I. Background
      a. Structural testing was added to the proposed work plan under Section 10 as an optional item for the vendors submitting materials
      b. Milliken and Stantec partnered to research
   II. Test Protocol Summary
      a. Refer to PowerPoint
   III. Unchanged from 2014 Work plan change is in section 3 and section 10
   IV. Open Discussion
      a. Chip Johnson
         i. Depending on the inherent strength of a material, the comparative nature of tensile versus compressive strength is a concern on the resin side of the marketplace
         ii. Add design parameters to the initial rather than within a percentage of the increase in load. This allows for the flexibility of the designing for the needs of a manufacturer’s client
      b. John Schuler – VDOT
         i. (AI) Move away from D790 and focusing more on the flexural modulus
      c. John Rublein WIDOT
         i. Given the variety of materials and material behaviors, expand on John Schuler’s comment
         ii. There will be others, they will behave differently

3) 10:55AM-11:10AM: Research - Jeff Syar
   a) Pooled Fund Research
      i) Pooledfund.org
ii) Commitment Required = $125K (5 DOT’s at $25k each)
   (1) Current partners are: Ohio, New York, and Pennsylvania.
   (2) Need two other partners to complete funding
iii) Develop structural design equations for spray applied liners
iv) Recommend material lab tests to perform on resin and cementitious materials
v) Recommend durability test to perform in the lab
vi) State funding match has been waived by the FHWA

4) 11:15AM-11:30AM: Millikan Research Presentation
   a) Miliken Geopolymers (Cementitious liner) Pipe Testing Results
      i) NTPEP - May 11, 2016
      ii) Create a method for the best method for design predictability results
      iii) Test project funded by Ontario and the transportation industry
           (1) Should the culverts be removed or rehabilitated?
           (2) Queens University was the host lab- Dr. Ian Moore
           (3) Load tested metal pipe with significant invert loss in soil cell that had cementitious spray applied liner installed
iv) Malaysia Testing results available
v) La Tech testing
   (1) Currently in the process of acquiring the remainder of the testing data
   (2) 18 pipe samples tested, compared to 5 models used by various engineers in the industry
   (3) Applied spray applied liner to the following material types:
      (a) Reinforced concrete pipe
      (b) Corrugated metal pipe
      (c) Cardboard sonotube

5) 11:30AM-11:45AM: Questions and Open Discussion
   a) Still analyzing the data on the cardboard sonotube lining
   b) A lot of the pipes being lined are pipe arches. This is why the distributed beam design approach was favored by Milliken
   c) John Rublein WIDOT
      i) Variability in tested behavior from empirical analysis
         (1) Issue: if you don’t have consistent boundary conditions, then the ability to predict based on reproducible research is not easily attained
      ii) Rourke’s model, used currently by industry, works on the foundation of uniform loading. Uniform loading is not a realistic way to bound your analysis
   d) Recommendation was made to add a parallel plate test to the structural portion for resin based materials that may fail under buckling (ie: flexural) versus cracking.
      i) Chip Johnson (Spray Roq) indicated that their material is capable of being sprayed onto cardboard sonotube.
      ii) Chip Johnson indicated Spray Roq material fails via cracking
      iii) John Rublein indicated that other resin based material may not fail under cracking
6) 11:45AM-11:50AM: Action Items for 2016-2017
   a) Add parallel plate test for resin based materials to test under structural section of workplan
   b) Send out the work plan for voting with the addition of the structural portion
   c) (AI) Identify the testing based on the failure mode for future evaluations
      i) D-Load would apply to Cementitious and Geopolymers
      ii) Cardboard Sonitude would be applicable for Resin based material that fail under buckling
   d) Implement a model that takes slope interactions into account- (ie: knee of the curve to indicated failure)
   e) Setup the next quarterly conference call as a follow-up to this meeting
Structural Testing for Spray Applied Liner

Jeffrey E. Syar, P.E.
Administrator, Office of Hydraulic Engineering
Background

- Structural testing was added to the proposed work plan under Section 10 as an optional item for the Vendors submitting materials.

- Testing is based on research that was performed by J. Royer (Milliken) and E. Allouche (Stantec) and presented at the 2016 North American Society for Trenchless Technology No-Dig Show.
Test Protocol Summary

- D-load testing of reinforced concrete pipes to the 0.01 inch

- Repair of the D-load tested reinforced concrete pipes to the manufacturer’s recommended thickness to restore strength

- Repair of the D-load tested reinforced concrete pipe to the manufacturer’s recommended thickness plus $\frac{1}{2}$ inch and plus 1 inch
Test Protocol Summary

- D-load testing of repaired reinforced concrete pipes to the 0.01 inch and to the ultimate load

- Test uses 6 reinforced concrete pipes (D-load 1000) at 48 inch diameters

- 8 foot sticks of pipe could be cut to 4 foot sections, reducing the number of sticks required if it’s cost effective and could still be D-load tested
Pooled Fund Research
Pooled Fund Research

- Structural Design Methodology for Spray Applied Pipe Liners in Gravity Storm Water Conveyance Conduits

- Anticipated to take 12 months to complete

- Ohio is the Lead state with the following partners: Pennsylvania and New York

- Looking for two more DOT partners
Pooled Fund Research

- Require 25k per DOT

- State funding has been waived by FHWA
  - Funded by 100% Federal funding that was allocated to the State for Research (ie: no State Match is Required)

- http://www.pooledfund.org/Details/Solicitation/1426
Objectives of Research

- Recommend a design methodology for both cementitious and resin based spray applied pipe liners for structural rehabilitation of gravity storm water conveyance conduits.

- Recommend a laboratory test method to verify the proposed structural design for conduits that have been rehabilitated using the spray applied pipe liner technology.
Objectives of Research

- Recommend an accelerated laboratory methodology to determine the liner material durability.

- Recommend laboratory material testing for both cementitious and resin based materials.
Scope of Work

.review multiple vendor suggested structural design methodologies for cementitious and resin based pipe liners. Ensure a minimum number of 4 vendors for cementitious and 4 vendors for resin based materials are solicited for input.

.review the Cured In Place (CIPP) design methodology outlined in ASTM F1216-09, Appendix X.1, equation X1.3. Review the design equations, variables, and assumptions to determine if the methodology is applicable for spray applied liners.

.review completed and active research that pertains to spray applied pipe liners.
Scope of Work

Survey US State DOT’s and Canadian Agencies to identify use and inspect a field installation of resin material and cementitious material.

Recommend a structural design methodology for cementitious and resin based spray applied liners that includes:
- LRFD Live and Dead Loads
- Host Conduit Conditions and Site Parameter assumptions
- Pipe Liner Material Properties

Develop an Excel Spreadsheet to calculate the required thickness for a cementitious and resin based spray applied liner pipe.
Scope of Work

- Recommend a laboratory test method to verify the structural design for conduits that have been rehabilitated using the spray applied pipe liner technology.

- Recommend an accelerated laboratory methodology to determine the liner material durability.

- Recommend laboratory material testing for both cementitious and resin based materials.
Questions?
Structural Testing:
407 Hwy Culverts

Queen’s University - Prof. Ian Moore
Testing Completed November 2013
Queen’s University Testing: Overview

• Damaged and deteriorated CMP culverts were excavated from the E407 Toll Road in Ontario, Canada.

• Two test culverts were assembled, buried and tested.

• The two culverts were then repaired with GeoSpray geopolymer mortar lining with nominal thickness of 50.8 mm (~2 inches) and 76.2 mm (~3 inches).

• Testing of the culverts was performed under single and double axle loads with buried depths of 1200 and 2100 mm (~48 and 83 inches) respectively.

• Finally, the culverts were loaded to the maximum available load conditions 1200 kN (~270,000 lbs-force).
Queen’s University Testing: Time Lapse View
Queen’s University Testing: Centrifugal Casting

(a) Beginning of repair

(b) Halfway through first pass

(c) Finishing pass

Source - Queens University - Ontario Canada - Ian Moore
Measured Response of 2 Deteriorated Metal Culverts Repaired with Sprayed Cementitious Liners
Queen’s University Testing: Completed Rehab

Source: Queens University - Ontario Canada - Ian Moore
Measured Response of 2 Deteriorated Metal Culverts Repaired with Sprayed Cementitious Liners
Queen’s University Testing: Results

- 50.8 mm (~2 inch) liner thickness:
  Initial signs of damage to the culvert under load were first observed at 650 kN (146,000 lbs-force) or 18% higher than the fully factored design load of 552 kN (~124,000 lbs-force).

- 76.2 mm (~3 inch) liner thickness:
  Initial signs of damage to the culvert under load were first observed at 800 kN (~180,000 lbs-force) or 45% higher than the fully factored design load of 552 kN (~124,000 lbs-force).

- Full report is now available.
Sirim QAS
RCP Testing

Malaysia - Completed December 2013
Sirim QAS RCP Testing: Experimental Overview

• 4 new RCP pipes 1.7 m (~67 inch) outer diameter, 1.5 m (~59 inch) inner diameter with a wall thickness of 200 mm (~8 inch) and 1 m in length (~39 inch) were coated with GeoSpray geopolymer mortar under the following conditions:
  » Sample 1 - Control Pipe - No Coating
  » Sample 2 - 50 mm (~2 inch) nominal coating
  » Sample 3 - 38 mm (~1.5 inch) nominal coating
  » Sample 4 - 38 mm (~1.5 inch) nominal coating with additional reinforced wire mesh

• Test were conducted under the following Malaysian standard
  » MS 881: Specification for Precast Concrete Pipes and Fittings for Drainage and Sewerage.
  » Part 3: Specification for pipes and fittings with Ogee Pipes
  » Appendix F: Crushing strength test for pipes.
Sirim QAS RCP Testing: Experimental Apparatus

4 New RCP Test Pipe Samples*

- Outer Diameter = 1.7 M (~67 inch)
- Wall Thickness = 200 mm (~8 inch)
- Inner Diameter = 1.5 M (~59 inch)
- Length = 1M (~39 inch)

*Coated with GeoSpray geopolymer

Source - Sirim QAS International Test Report No: 2013-CB4822
### Test Results

<table>
<thead>
<tr>
<th>Sample</th>
<th>Description</th>
<th>First Crack (%)</th>
<th>Ultimate Load (%)</th>
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</thead>
<tbody>
<tr>
<td><strong>Sample 1</strong></td>
<td>Control Pipe - No Coating</td>
<td>Tested</td>
<td>Tested</td>
</tr>
<tr>
<td><strong>Sample 2</strong></td>
<td>50 mm (~2 inch) nominal coating</td>
<td>First Crack +122%; UL +268%</td>
<td>Tested</td>
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<tr>
<td><strong>Sample 3</strong></td>
<td>38 mm (~1.5 inch) nominal coating</td>
<td>First Crack +98%; UL +209%</td>
<td>Tested</td>
</tr>
<tr>
<td><strong>Sample 4</strong></td>
<td>38 mm (~1.5 inch) nominal coating with additional reinforced wire mesh</td>
<td>First Crack +24%; UL +277%</td>
<td>Tested</td>
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</table>

<table>
<thead>
<tr>
<th>Test Sample</th>
<th>Weight (kg)</th>
<th>Proof Load (kN)</th>
<th>Ultimate Load (kN)</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. C1 - Untreated Precast Concrete Pipe</td>
<td>1875</td>
<td>45</td>
<td>53</td>
<td>The width of 0.5 mm crack is identified at the bottom side.</td>
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<td>2. C2 - Precast Concrete Pipe Treated with 50 mm thickness of GeoSpray</td>
<td>2842</td>
<td>100</td>
<td>195</td>
<td>The width of 0.26 mm crack is identified at the bottom side.</td>
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<tr>
<td>3. C3 - Precast Concrete Pipe Treated with 38 mm thickness of GeoSpray</td>
<td>2663</td>
<td>80</td>
<td>164</td>
<td>The width of 0.06 mm crack is identified at the top and bottom sides.</td>
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<tr>
<td>4. C4 - Precast Concrete Pipe Treated with 38 mm thickness of GeoSpray and Reinforced with wire mesh</td>
<td>2565</td>
<td>56</td>
<td>200</td>
<td>The width of 0.02 mm crack is identified at the top and bottom sides.</td>
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</table>

Source - Sirim QAS International Test Report No: 2013-CB4822
The goal of the project was to validate proposed engineering methodologies for structural rehabilitation of large diameter pipes with experimental data.

This study tested the effects of:
- Liner Thickness
- Pipe Diameter (24” – 48”)
- Ovality
- Pipe Type (RCP, CMP, Cardboard)

All RCP pipes were pre-broken prior to repair.
Each 8ft Section of RCP had the collar removed and then was cut approximately in half.
All tests were performed under the ASTM C497 “D-Load” method.
Each pipe was then pre-stressed until a D-Load crack was present in the crown, invert and the external side of both spring-lines.
La Tech - TTC: Experimental Parameters

The full suite of rehabilitated pipes
The experimental apparatus included the ability to use video monitoring of the shear stresses in the structure during loading.
La Tech - TTC: New vs Rehabilitated Pipe Curves

D-Load Testing of Rehabilitated 36" ID Pipes
2" GeoPolymer Liner Thickness

- Rehabilitated RCP
- New RCP

Load (lbs)

Deflection (in)
### TTC: RCP Test Matrix with Results

<table>
<thead>
<tr>
<th>Pipe Type</th>
<th>Pipe OD (inch)</th>
<th>Pipe ID (inch)</th>
<th>Length (ft)</th>
<th>Liner Thickness (inch)</th>
<th>D-Load (lbs)</th>
<th>D-Load (psi)</th>
<th>Deflection @ D-Load (in)</th>
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</thead>
<tbody>
<tr>
<td>RCP</td>
<td>26.5</td>
<td>24.0</td>
<td>3.7</td>
<td>0.00</td>
<td>11700</td>
<td>75</td>
<td>0.24</td>
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<tr>
<td>RCP</td>
<td>26.5</td>
<td>24.0</td>
<td>3.7</td>
<td>0.00</td>
<td>17400</td>
<td>112</td>
<td>0.19</td>
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<tr>
<td>RCP</td>
<td>39.0</td>
<td>36.0</td>
<td>3.7</td>
<td>0.00</td>
<td>12800</td>
<td>82</td>
<td>0.32</td>
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<tr>
<td>RCP</td>
<td>52.0</td>
<td>48.0</td>
<td>3.7</td>
<td>0.00</td>
<td>18000</td>
<td>116</td>
<td>0.26</td>
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<tr>
<td>RCP</td>
<td>26.5</td>
<td>24.0</td>
<td>3.7</td>
<td>0.66</td>
<td>12800</td>
<td>82</td>
<td>0.41</td>
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<tr>
<td>RCP</td>
<td>26.5</td>
<td>24.0</td>
<td>3.7</td>
<td>0.66</td>
<td>10800</td>
<td>69</td>
<td>0.26</td>
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<tr>
<td>RCP</td>
<td>26.5</td>
<td>24.0</td>
<td>3.7</td>
<td>1.33</td>
<td>21700</td>
<td>140</td>
<td>0.37</td>
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<tr>
<td>RCP</td>
<td>39.0</td>
<td>36.0</td>
<td>3.7</td>
<td>1.33</td>
<td>15100</td>
<td>97</td>
<td>0.32</td>
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<tr>
<td>RCP</td>
<td>39.0</td>
<td>36.0</td>
<td>3.7</td>
<td>1.00</td>
<td>15100</td>
<td>97</td>
<td>0.38</td>
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<tr>
<td>RCP</td>
<td>39.0</td>
<td>36.0</td>
<td>3.7</td>
<td>1.50</td>
<td>21000</td>
<td>135</td>
<td>0.38</td>
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<tr>
<td>RCP</td>
<td>39.0</td>
<td>36.0</td>
<td>3.7</td>
<td>2.00</td>
<td>20300</td>
<td>131</td>
<td>0.42</td>
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<tr>
<td>RCP</td>
<td>39.0</td>
<td>36.0</td>
<td>3.7</td>
<td>2.00</td>
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<td>164</td>
<td>0.60</td>
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<td>48.0</td>
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<td>1.33</td>
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<td>103</td>
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<td>RCP</td>
<td>52.0</td>
<td>48.0</td>
<td>3.7</td>
<td>1.33</td>
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<td>120</td>
<td>0.34</td>
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<tr>
<td>RCP</td>
<td>52.0</td>
<td>48.0</td>
<td>3.7</td>
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<td>183</td>
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<td>RCP</td>
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<td>48.0</td>
<td>3.7</td>
<td>2.66</td>
<td>35800</td>
<td>230</td>
<td>0.52</td>
</tr>
</tbody>
</table>
Moment $M = I / (c \cdot S_F)$

$I = t^3 / 12$

But do we really know where the neutral axis is? It is more conservative to assume that it is not at the mid-point of the liner but at the interface so we will assume $c = t$

Moment $= t^2 / (12 \cdot S_f)$

$E_L$ - Elastic Modulus
$S_F$ - Flexural Strength
$S_T$ - Tensile Strength
$N$ - Safety Factor
$C$ - Ovality Reduction Factor (ASTM F-1216)
$P$ - Total Load
$\mu$ - Poisson's Ratio
19. Thin tube under uniform lateral external pressure (radius of tube = r)

\[
t = 2.5 \sqrt{\frac{Plr^{1.5}(1 - \mu^2)^{0.75} N}{0.807 \times E_L \times C}}
\]

Assumes Ends are held constrained at distance L

Source - Roark's Formulas for Stress and Strain - Young et al.
Moment at Invert
Is Maximum

\[ Pr^2 \left( \frac{2}{3} + \frac{3\pi}{8} \right) / \pi = 0.5872 Pr^2 \]

Using the relation

\[ w = c \left[ \frac{M}{I E} \right] \]

Where \( w \) is the crack width

\[ t = \sqrt{\frac{7.0464 P r^2 N}{w E_L \frac{C}{C}}} \]

Engineers have suggest \( w = 0.01 \) & \( 0.0625 \)

Source - Structural Mechanics of Buried Pipes - Watkins & Anderson
The resultant solution for this case is:

\[ t = \sqrt{\frac{0.0744 \, P \, r^2 \, N}{S_F \, C}} \]
\[
\frac{6Pr N}{\pi t^2 C} = B_S T \left(1 + \frac{t}{\lambda_0 d_a}\right)^{-\frac{1}{2}}
\]

Where \( B \) & \( \lambda_0 \) are regression constants & \( d_a \) is the size of the largest aggregate.

This is in the form of a quadratic equation with 4 roots only 1 is real and positive.

Size Effect in Brittle Failure of Unreinforced Pipes

by Zdenek P. Bazant and Zhiming Cao

Fracture mechanics aspects of the failure of unreinforced concrete structures have long been of interest to engineers and architects. The more important consequences of fracture mechanics is the improvement of the design of concrete structures. According to fracture mechanics, the nominal stress at failure decreases as the size of the member increases. This effect has been demonstrated not only for notched fracture specimens, but also for unnotched concrete specimens. The improved stress-strain curve of concrete at failure is probably the most characteristic feature of the stress-strain curve of concrete. The present study demonstrates the effect of unreinforced concrete pipes.

Unreinforced concrete pipes exhibit basically two modes of failure: bond failure (Fig. 1a) and ring failure (Fig. 1b). Test results show that the nominal stress at failure for the bond failure is much less than for the ring failure, and that for the ring failure the nominal stress at failure decreases as the pipe diameter or thickness increases. Therefore, different strength values have been considered for various locations. Contradictory and Hiltberg, however, have recently demonstrated that the existing test results are consistent with unique sets of material strength characteristics provided that nonlinear fracture mechanics is applied. Otsuji et al. A new model for the size effect on the strength of unreinforced concrete pipes was proposed by Otsuji et al. (1983). The model is based on the observation that the size effect on the strength of unreinforced concrete pipes is more pronounced than for reinforced concrete pipes. The model is based on the observation that the size effect on the strength of unreinforced concrete pipes is more pronounced than for reinforced concrete pipes.

SIZE EFFECT LAW

Due to its heterogeneous and discontinuous nature, the fracture propagation in concrete is controlled by dispersed

- Source - Size Effect in Brittle Failure of Unreinforced Pipes - ACI Journal May-June 1966
Each RCP pipe was preloaded and then rehabilitated and then loaded again.

The D-Load Values were scaled with the bedding factor $B_f$ - We assumed Type IV bedding ($B_f = 1.5$) (Source: Concrete Pipe Design Manual).

The following physical properties measured by a third party certified laboratory were used as the values for the material in the models.

<table>
<thead>
<tr>
<th>Property</th>
<th>Test Method</th>
<th>Duration</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compression Strength</td>
<td>ASTM C109</td>
<td>28 Day</td>
<td>8000 psi</td>
</tr>
<tr>
<td>Flexural Strength</td>
<td>ASTM C78</td>
<td>28 Day</td>
<td>1800 psi</td>
</tr>
<tr>
<td>Elastic Modulus</td>
<td>ASTM C469</td>
<td>28 Day</td>
<td>5,800,000 psi</td>
</tr>
<tr>
<td>Aggregate Size</td>
<td>ASTM C33</td>
<td></td>
<td>2.38 mm</td>
</tr>
<tr>
<td>Poisson Ratio</td>
<td>ASTM C469</td>
<td>28 Day</td>
<td>0.19</td>
</tr>
<tr>
<td>Tensile Strength</td>
<td>ASTM C307</td>
<td>28 Day</td>
<td>850 psi</td>
</tr>
</tbody>
</table>
Comparison of Model Thickness Predictions to Scaled D-Load Test Data for RCP Pipes using $B_f=1.5$ at 24 Inch Diameter

- D-Load*BF
- Crack 0.01
- Bazant-Cao
- Distributed Beam
- Crack 0.0625
- Roark's

Source - NASST No DIG 2016, Dallas TX - Paper No WM-T6-03 (Royer & Allouche)
Comparison of Model Thickness Predictions to Scaled D-Load Test Data for RCP Pipes using $B_f=1.5$ at 36 Inch Diameter

Source - NASST No DIG 2016, Dallas TX - Paper No WM-T6-03 (Royer & Allouche)
Comparison of Model Thickness Predictions to Scaled D-Load Test Data for RCP Pipes using $B_f=1.5$ at 48 Inch Diameter
Design Pressures of Buried Pipes
(Assumes GWT at free surface - AASHTO LRFD Loadings)

Source - NASST No DIG 2016, Dallas TX - Paper No WM-T6-03 (Royer & Allouche)
This model gives a good representation of the data and is more conservative as pipe size increases under typical loads.
This model is less conservative at typical field conditions as pipe diameter increases.

![Design Thickness of Buried Pipes graph](image-url)
18 RCP Pipe Samples were tested and evaluated. They were compared to 5 models that have been used for design by various engineers in the industry. The 0.01 Crack Model is the most conservative with a significant over design in all cases (well above the safety factor of 2.0). The Bazant – Cao Model is generally conservative and predictive for pipes in the size range tested, but becomes less conservative as the pipes increase in size greater than 48”. The Distributed Beam over a Partial Ring Model is less conservative at lower pipe sizes but becomes predictive and more conservative as the pipe size increases. All 3 of these models give reasonable predictions in the range of typical design pressures (below 50 psi).
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<th>Last Name</th>
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<td>Robert</td>
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