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) **Malayasia 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) **Cardboad 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 ½ 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.

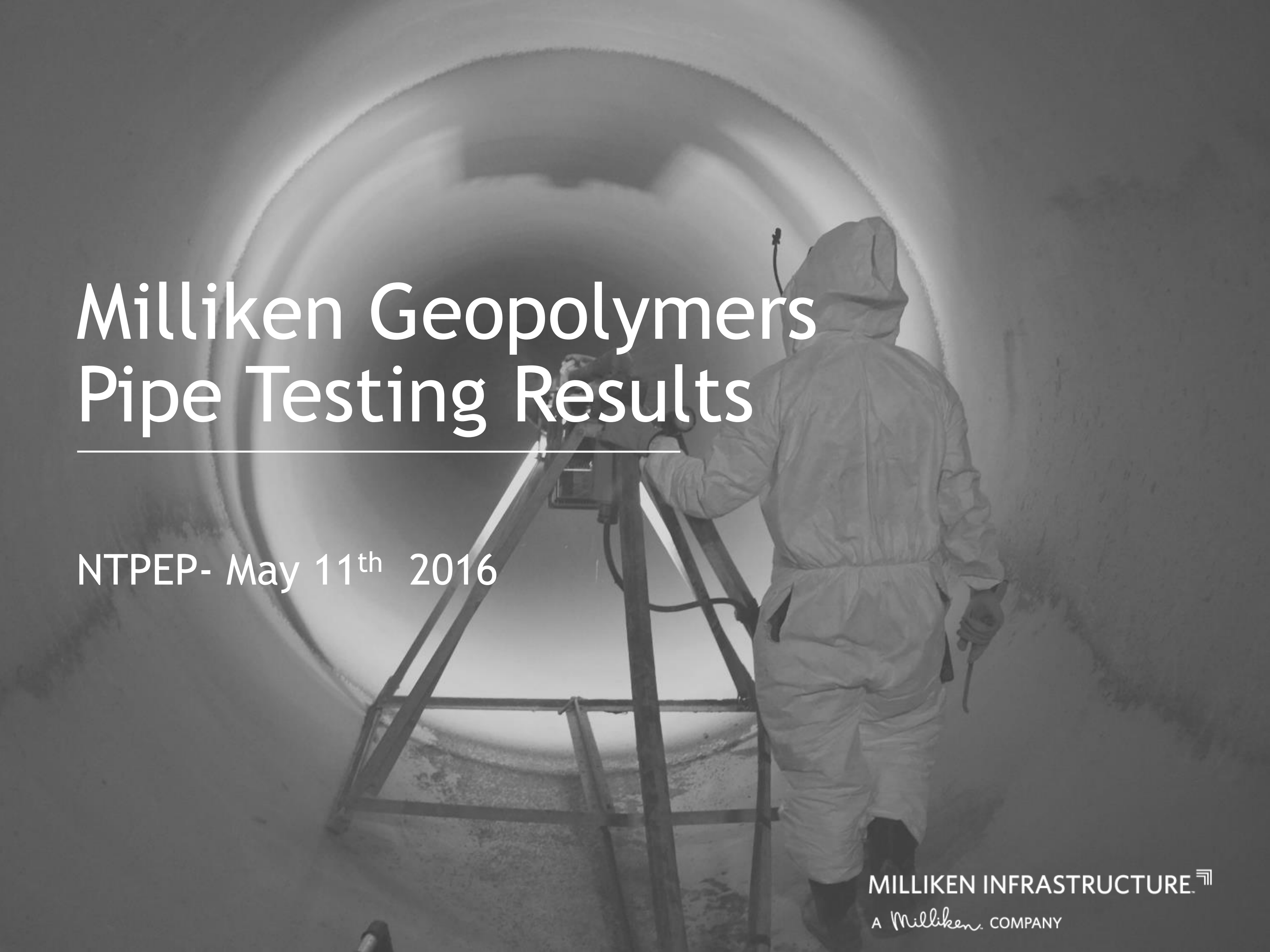
Scope of Work

- 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?



Milliken Geopolymers Pipe Testing Results

NTPEP- May 11th 2016

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Structural Testing: 407 Hwy Culverts

Queen’s University – Prof. Ian Moore

Testing Completed November 2013

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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).

Source - Queens University - Ontario Canada - Ian Moore
Measured Response of 2 Deteriorated Metal Culverts Repaired with Sprayed Cementitious Liners

Queen’s University Testing: Instrumentation

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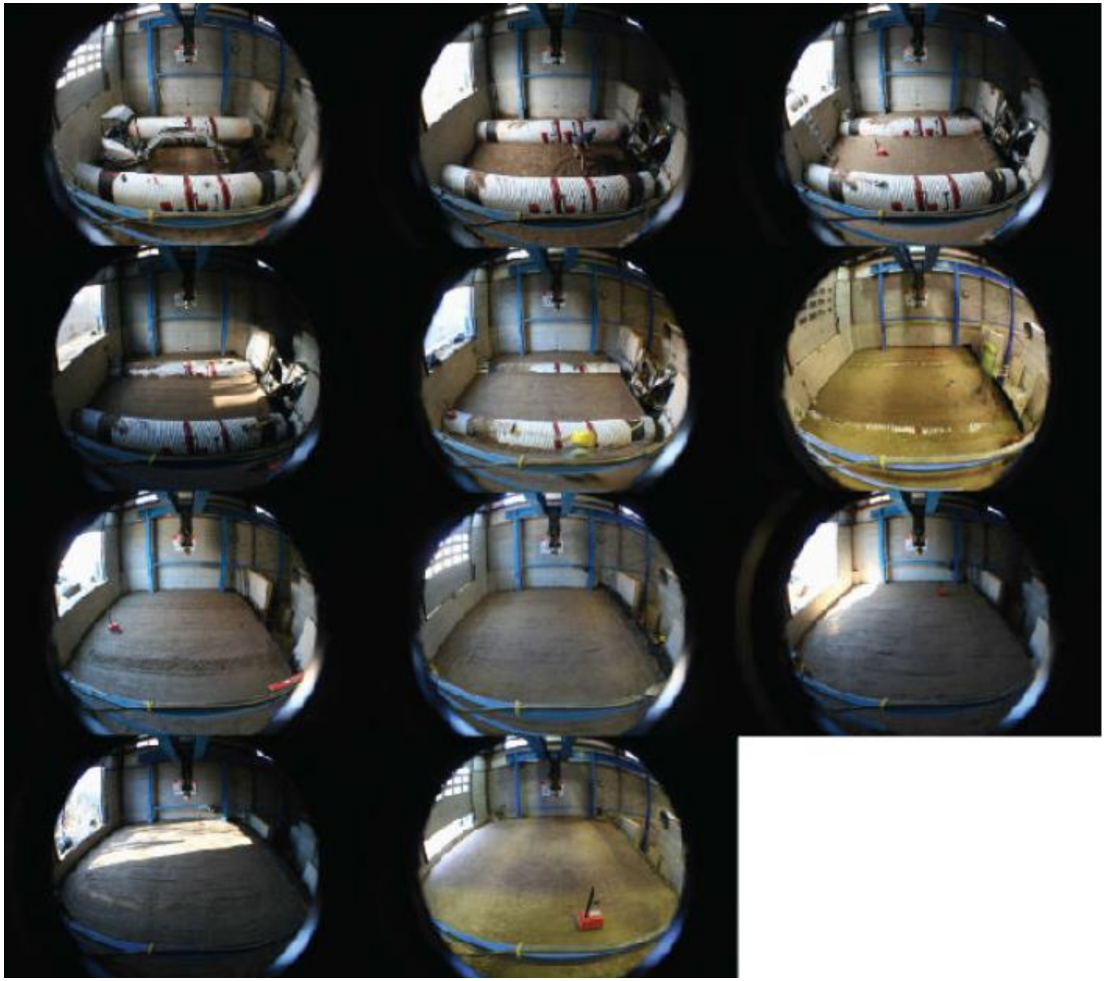
Source - Queens University - Ontario Canada - Ian Moore
Measured Response of 2 Deteriorated Metal Culverts Repaired with Sprayed Cementitious Liners

Queen’s University Testing: Time Lapse View



Source - Queens University - Ontario Canada - Ian Moore
Measured Response of 2 Deteriorated Metal Culverts Repaired with Sprayed Cementitious Liners

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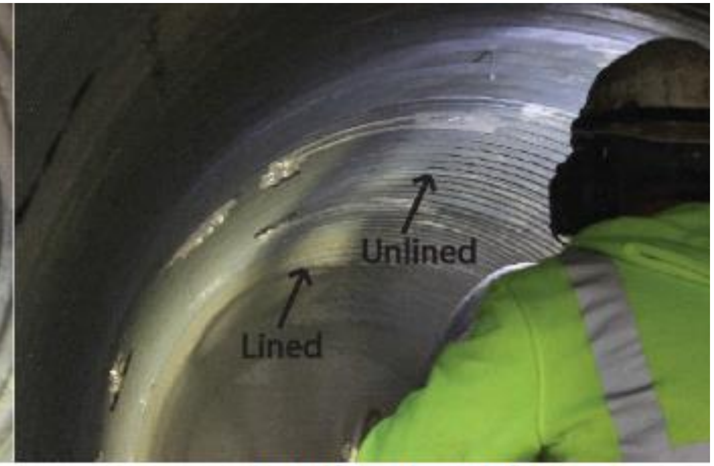
Queen’s University Testing: Centrifugal Casting

(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.

Source - Queens University - Ontario Canada - Ian Moore
Measured Response of 2 Deteriorated Metal Culverts Repaired with Sprayed Cementitious Liners

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.

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

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

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

Sirim QAS International Testing

NO	TEST RESULT				REMARK
	Test Sample	Weight (kg)	Proof Load (kN) First Crack Observed	Ultimate Load (kN)	
1.	C1 - Untreated Precast Concrete Pipe	1875	45	53	The width of 0.5 mm crack is identified at the bottom side
2.	C2 - Precast Concrete Pipe Treated with 50 mm thickness of GeoSpray	2842	100	195	The width of 0.26 mm crack is identified at the bottom side
3.	C3 - Precast Concrete Pipe Treated with 38 mm thickness of GeoSpray	2663	89	164	The width of 0.06 mm crack is identified at the top and bottom sides
4.	C4 - Precast Concrete Pipe Treated with 38 mm thickness of GeoSpray and Reinforced with wire mesh	2565	56	200	The width of 0.02 mm crack is identified at the top and bottom sides

Sample 1 Control Pipe – No Coating

Sample 2 50 mm (~2 inch) nominal coating
First Crack +122%; UL +268%

Sample 3 38 mm (~1.5 inch) nominal coating
First Crack +98%; UL +209%

Sample 4 38 mm (~1.5 inch) nominal coating with additional reinforced wire mesh
First Crack +24%; UL +277%

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

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La Tech
TTC
Design Model Testing

Comparative Engineering Models

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La Tech – TTC: Experimental Outline

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.

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La Tech – TTC: Experimental Parameters

Each 8ft Section of RCP had the collar removed and then was cut approximately in half.

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Source – NASST No DIG 2016, Dallas TX – Paper No WM-T6-03 (Royer & Allouche)

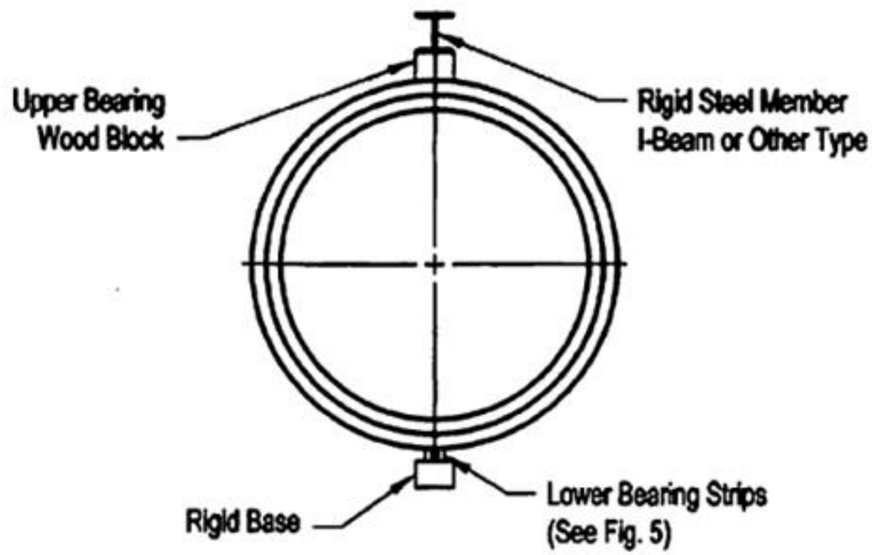
La Tech – TTC: D-Load Testing Standard

All tests were performed under the ASTM C497 "D-Load" method.

Designation: C497 – 13

Standard Test Methods for Concrete Pipe, Manhole Sections, or Tile[1]

This standard is issued under the fixed designation C497; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.



Source – NASST No DIG 2016, Dallas TX – Paper No WM-T6-03 (Royer & Allouche)

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La Tech – TTC: Experimental Parameters

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

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La Tech – TTC: Experimental Parameters

The full suite of rehabilitated pipes

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La Tech – TTC: Experimental Parameters

The experimental apparatus included the ability to use video monitoring of the shear stresses in the structure during loading

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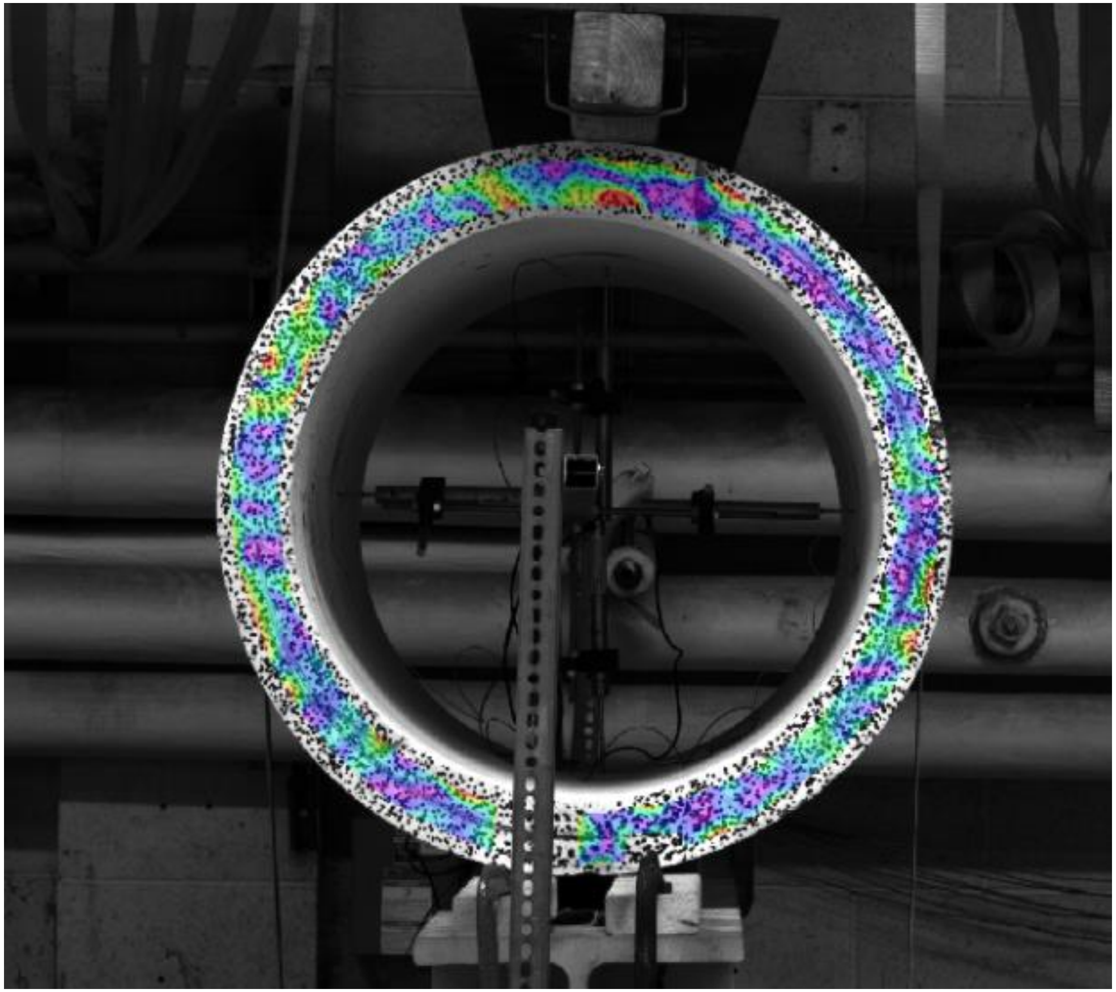
Source – NASST No DIG 2016, Dallas TX – Paper No WM-T6-03 (Royer & Allouche)

La Tech – TTC: Experimental Parameters



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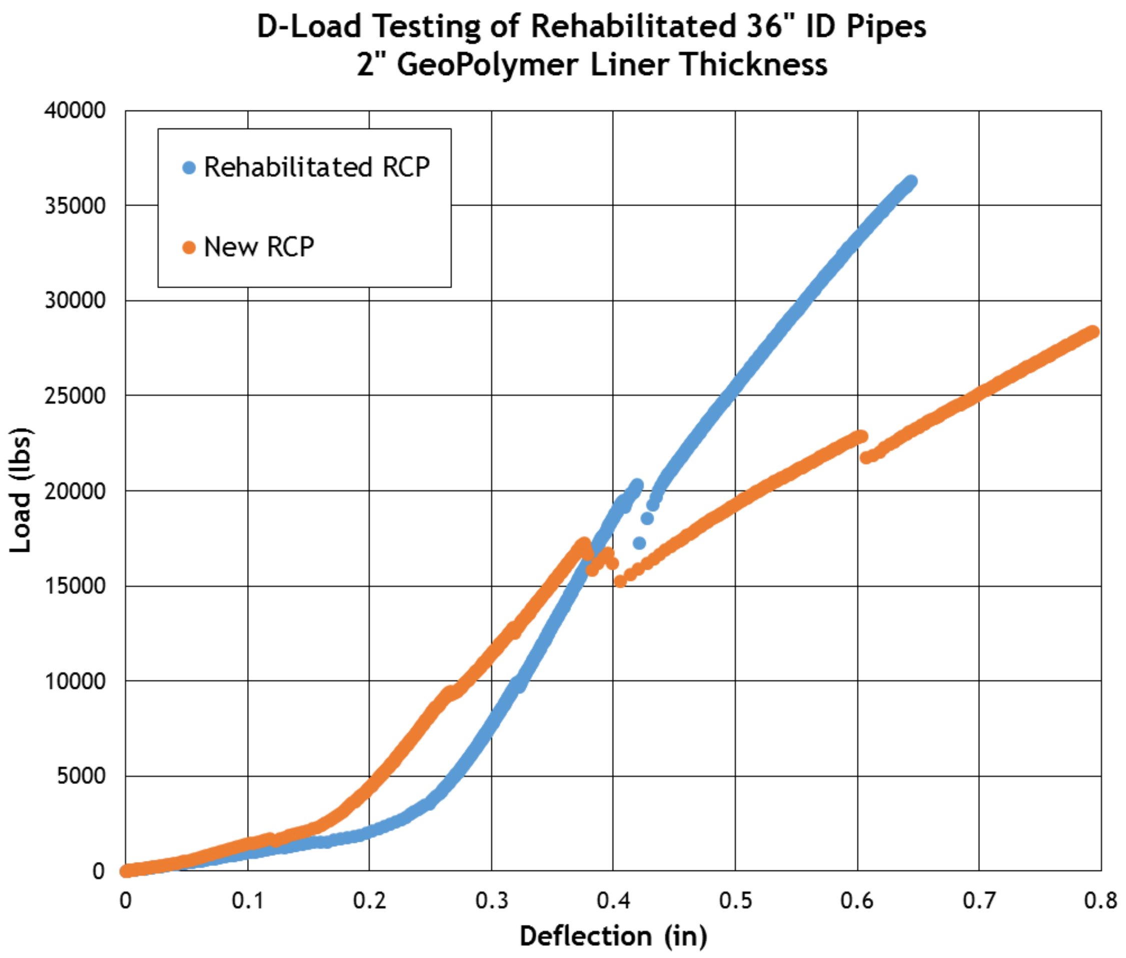
Source – NASST No DIG 2016, Dallas TX – Paper No WM-T6-03 (Royer & Allouche)

La Tech – TTC: New *vs* Rehabilitated Pipe Curves



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La Tech – TTC: RCP Test Matrix with Results

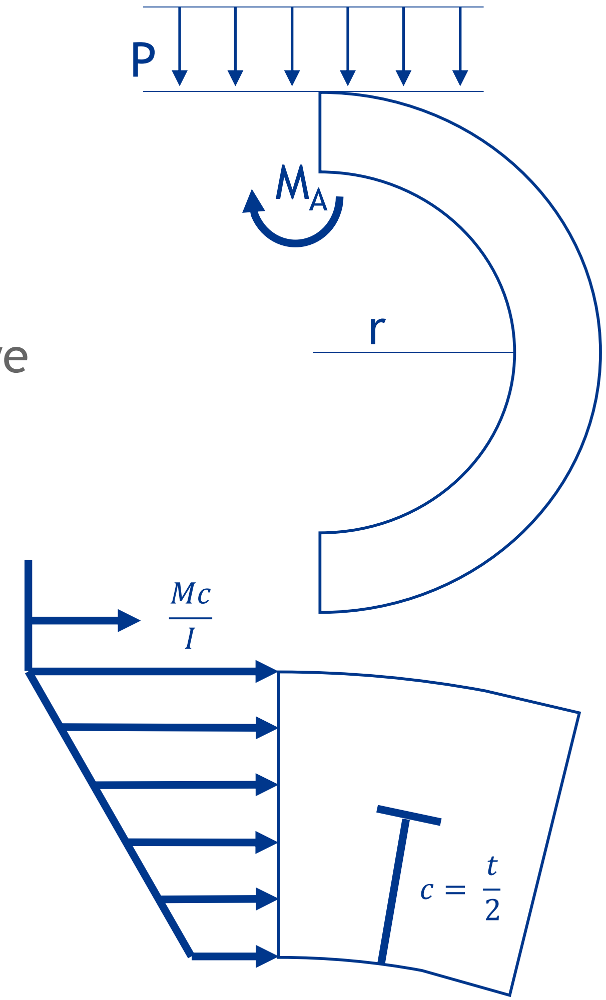
Pipe Type	Pipe OD	Pipe ID	Length	Liner Thickness	D-Load	D-Load	Deflection @ D-Load
	(inch)	(inch)	(ft)	(inch)	(lbs)	(psi)	(in)
RCP	26.5	24.0	3.7	0.00	11700	75	0.24
RCP	26.5	24.0	3.7	0.00	17400	112	0.19
RCP	39.0	36.0	3.7	0.00	12800	82	0.32
RCP	52.0	48.0	3.7	0.00	18000	116	0.26
RCP	52.0	48.0	3.7	0.00	20700	133	0.24
RCP	26.5	24.0	3.7	0.66	12800	82	0.41
RCP	26.5	24.0	3.7	0.66	10800	69	0.26
RCP	26.5	24.0	3.7	1.33	21700	140	0.37
RCP	26.5	24.0	3.7	1.33	15100	97	0.32
RCP	39.0	36.0	3.7	1.00	15100	97	0.38
RCP	39.0	36.0	3.7	1.00	17500	113	0.38
RCP	39.0	36.0	3.7	1.50	21000	135	0.38
RCP	39.0	36.0	3.7	2.00	20300	131	0.42
RCP	39.0	36.0	3.7	2.00	25500	164	0.60
RCP	52.0	48.0	3.7	1.33	16000	103	0.36
RCP	52.0	48.0	3.7	1.33	18700	120	0.34
RCP	52.0	48.0	3.7	2.66	28500	183	0.46
RCP	52.0	48.0	3.7	2.66	35800	230	0.52

La Tech – TTC: Design Model Assumptions

Moment $M=I/(c*S_F)$
$I = t^3/12$

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 = $t^2/(12*S_f)$
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
μ – Poisson's Ratio



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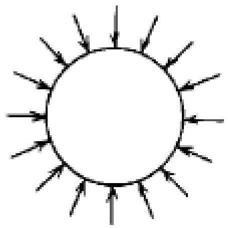
Source – NASST No DIG 2016, Dallas TX – Paper No WM-T6-03 (Royer & Allouche)

La Tech – TTC: Model 1 – Uniform Lateral Pressure

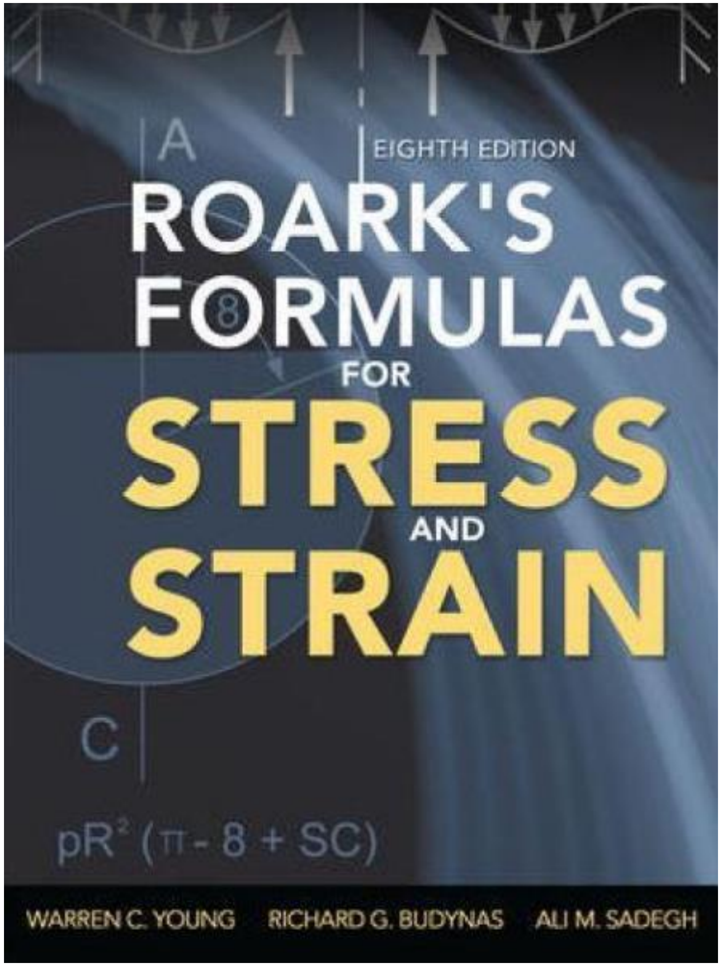
19. Thin tube under uniform lateral external pressure (radius of tube = r)



$\frac{r}{t} > 10$

Assumes Ends are held constrained at distance L

$$t = \sqrt[2.5]{\left(\frac{PLr^{1.5}(1-\mu^2)^{0.75}}{0.807 * E_L}\frac{N}{C}\right)}$$



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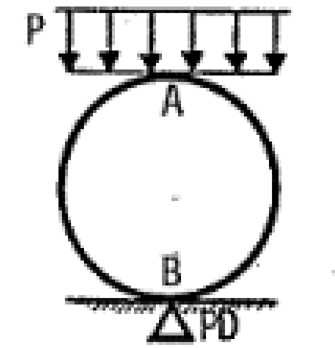
Source – Roark's Formulas for Stress and Strain – Young et. al.

La Tech – TTC: Model 2 – Cracking



Moment at Invert
Is Maximum

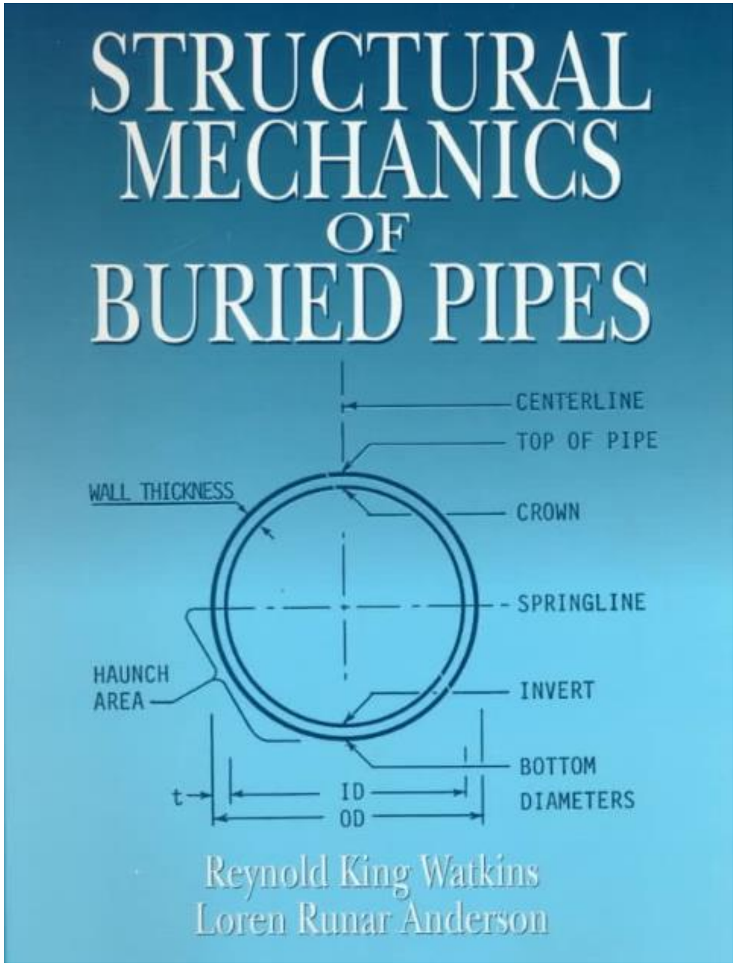
$$Pr^2(2/3+3\pi/8)/\pi$$
$$= 0.5872Pr^2$$

Using the relation $$w = c\left[\frac{M}{IE}\right]$$

Where *w* is the crack width

$$t = \sqrt{\frac{7.0464\,P\,r^2}{wE_L}\frac{N}{C}}$$

Engineers have suggest w = 0.01 & 0.0625



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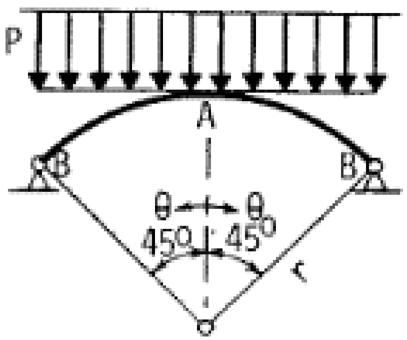
Source – Structural Mechanics of Buried Pipes – Watkins & Anderson

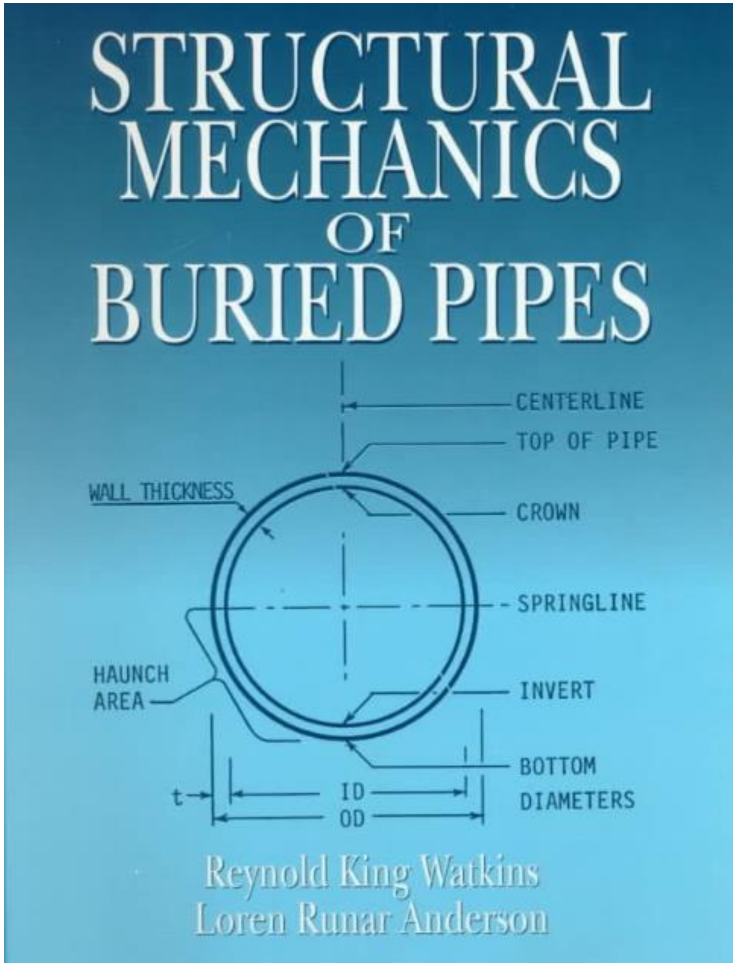
La Tech – TTC: Model 3 – Circular Arch with Beam Load



$$T_A = 0.8323Pr$$
$$M_A = 0.0062Pr^2$$

The resultant solution for this case is:

$$t = \sqrt{\frac{0.0744\,P\,r^2}{S_F}\frac{N}{C}}$$



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La Tech – TTC: Model 4 – Baz-Cao Scaling

$$\frac{6Pr}{\pi t^2}\frac{N}{C} = BS_T\left(1+\frac{t}{\lambda_o d_a}\right)^{-\frac{1}{2}}$$

Where B & λ_o 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.

ACI JOURNAL TECHNICAL PAPER
Title no. 83-36

Size Effect in Brittle Failure of Unreinforced Pipes

by Zdeněk P. Bažant and Zhiping Cao

Unreinforced concrete pipes basically can fail in two modes: beam failure and ring failure. According to the existing test data, the nominal stress at beam failure is much less than that at ring failure. Furthermore, the nominal stress for either failure mode decreases as the pipe diameter or thickness increases. These size effects can be described in a unified manner by means of the recently established size-effect law for failures which are preceded by the formation of microcracking zones. A simple formula involving the size effect is proposed and is justified by comparisons with existing test data.

Keywords: concrete pipes; cracking (fracturing); dimensional analysis; failure; microcracking; regression analysis; stresses; structural analysis.

Fracture mechanics aspects of the failure of unreinforced as well as reinforced concrete structures are now coming to the center of attention. The most important consequence of fracture mechanics is the structural size effect in failure. According to limit analysis as well as allowable stress design, geometrically similar structures of different sizes fail at the same nominal stress. However, according to fracture mechanics, the nominal stress at failure decreases as the size of the structure increases. This effect has been demonstrated not only for notched fracture specimens, but also for diagonal shear failure of longitudinally reinforced beams, unprestressed as well as prestressed, and it probably is characteristic of all brittle failures of concrete structures. The present study demonstrates the effect for unreinforced concrete pipes.

Unreinforced concrete pipes exhibit basically two modes of failure: beam failure [Fig. 1(a)] and ring failure [Fig. 1(b)]. Test results show that the nominal stress at failure for the beam failure is much less than for the ring failure, and that for either case the nominal stress at failure decreases as the pipe diameter or thickness increases. Therefore, different strength values have been considered for various situations. Gustafsson[1] and Hillerborg,[2] however, have recently demonstrated that the existing test results are consistent with unique values of material strength characteristics provided that nonlinear fracture mechanics is applied. Gustafsson established this with the help of the finite element fictitious crack model of Hillerborg, and the same can be shown to be true for the crack band finite element model.[4-7] The objective of this study is not finite element analysis but development of an approximate simple formula for design.

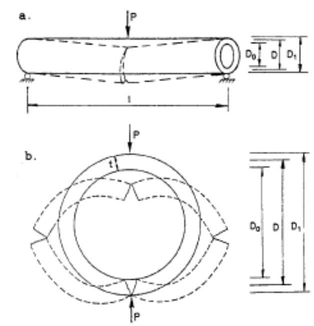

Fig. 1 — Beam and ring failures of pipe

SIZE EFFECT LAW

Due to its heterogeneity and brittleness, fracture propagation in concrete is preceded by dispersed mi-

Received Mar. 25, 1985, and reviewed under Institute publication policies. Pertinent discussion will be published in the March-April 1987 ACI JOURNAL if received by Dec. 1, 1986.

Source – Size Effect in Brittle Failure of Unreinforced Pipes – ACI Journal May-June 1966

La Tech – TTC: Evaluating the Models against Data

- 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.

Property	Test Method	Duration	Value
Compression Strength	ASTM C109	28 Day	8000 psi
Flexural Strength	ASTM C78	28 Day	1800 psi
Elastic Modulus	ASTM C469	28 Day	5,800,000 psi
Aggregate Size	ASTM C33		2.38 mm
Poisson Ratio	ASTM C469	28 Day	0.19
Tensile Strength	ASTM C307	28 Day	850 psi

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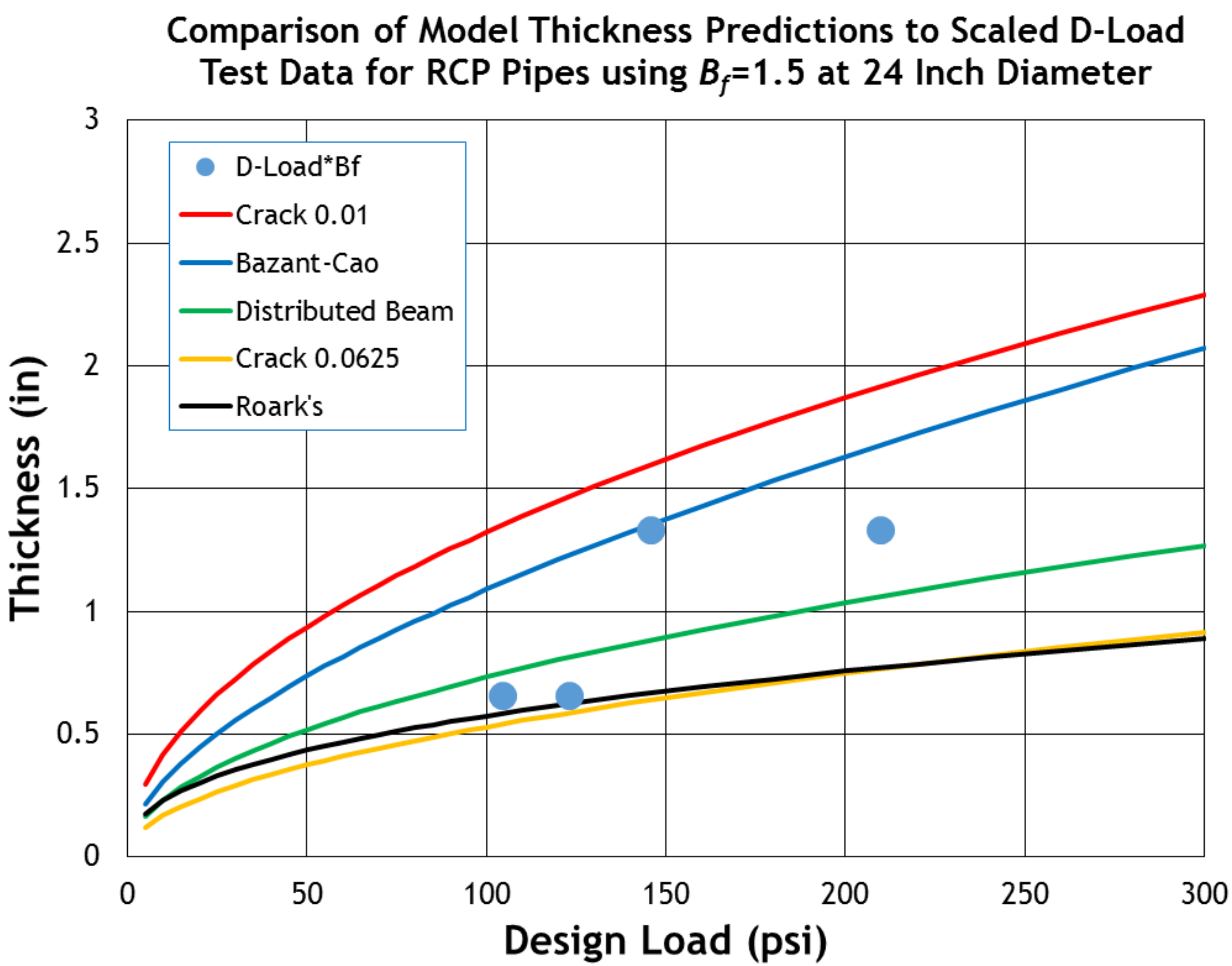
Source – NASST No DIG 2016, Dallas TX – Paper No WM-T6-03 (Royer & Allouche)

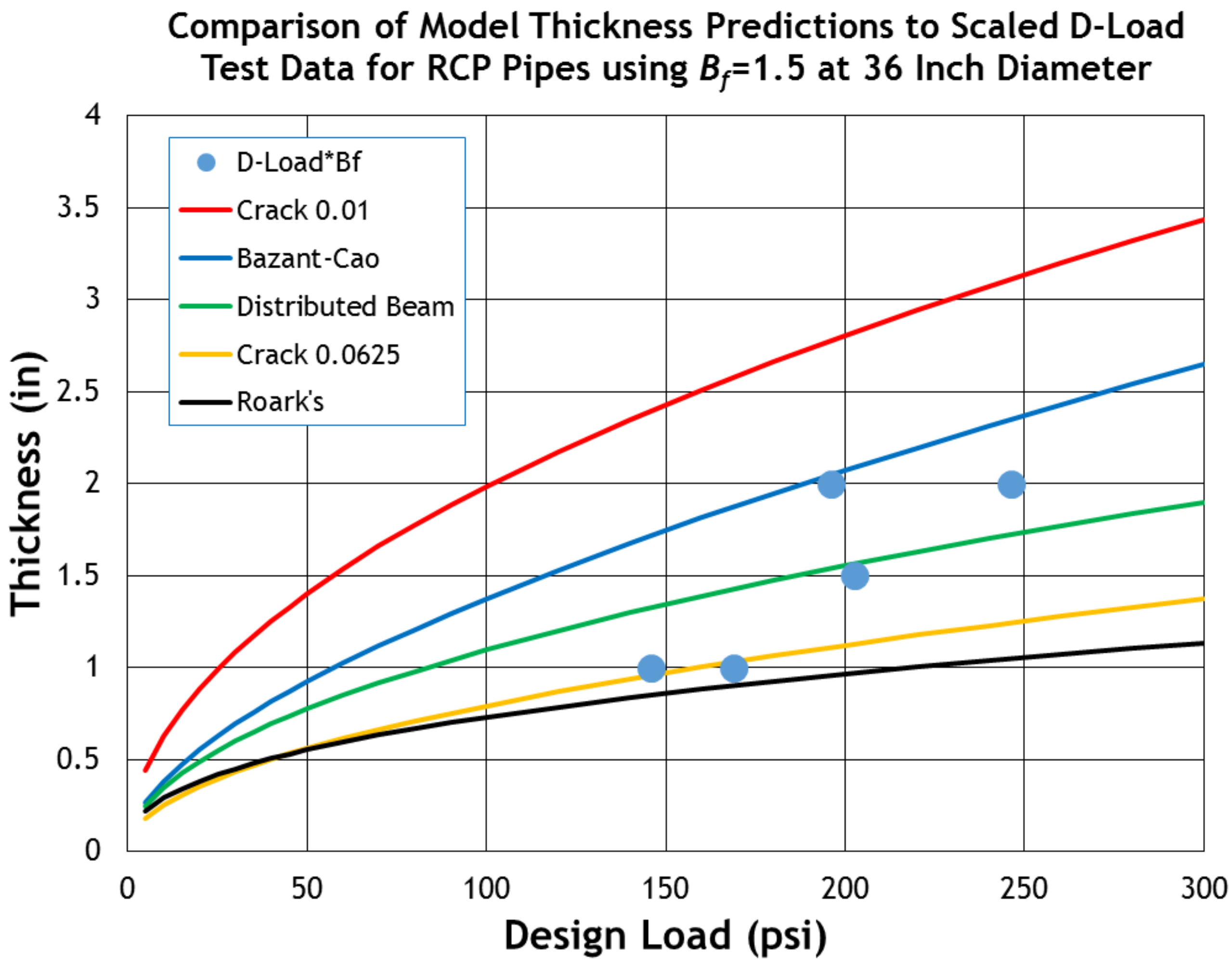
La Tech – TTC: Data Comparison to Model Predictions – 24”



MILLIKEN INFRASTRUCTURE
A Milliken COMPANY

Source – NASST No DIG 2016, Dallas TX – Paper No WM-T6-03 (Royer & Allouche)

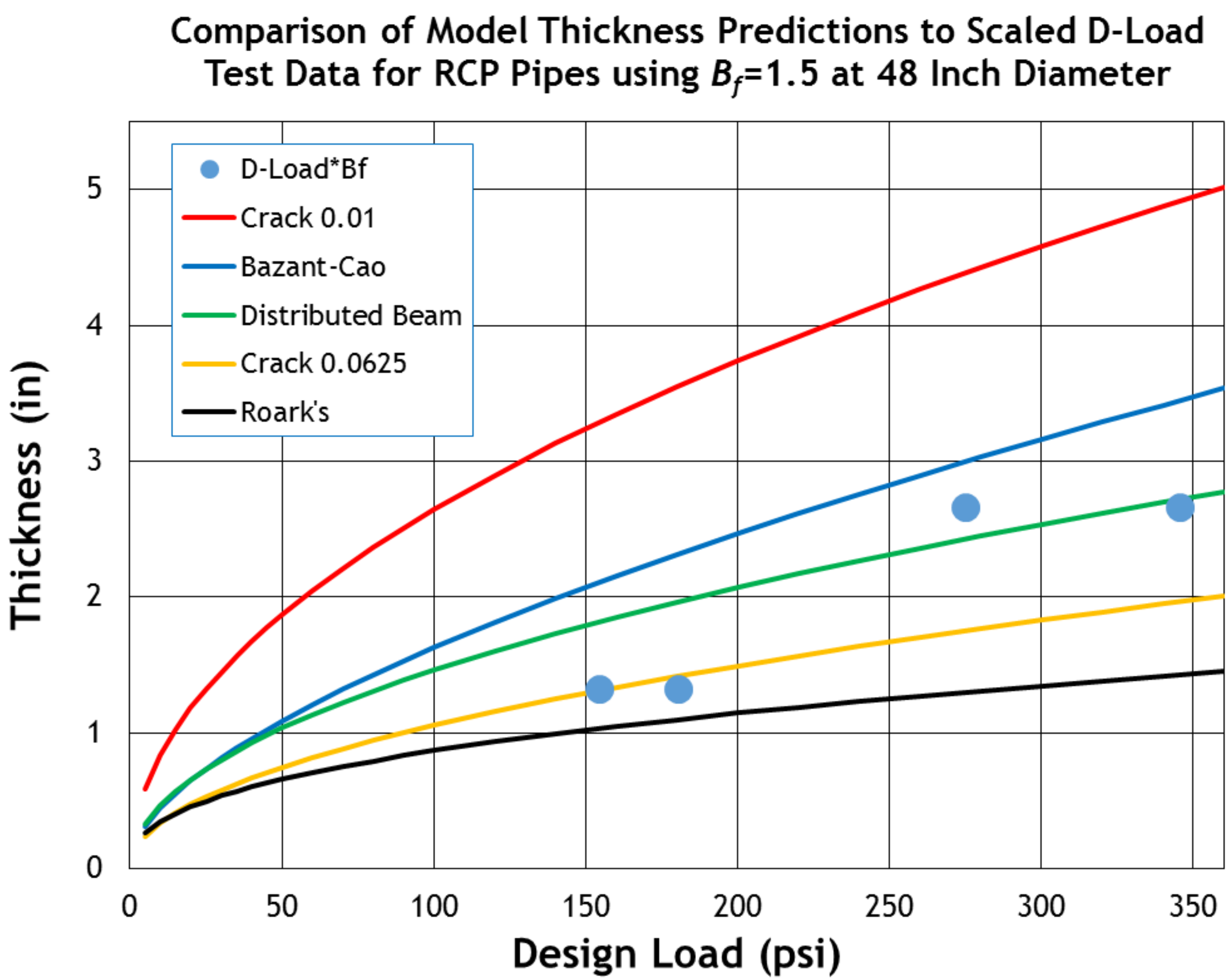
La Tech – TTC: Data Comparison to Model Predictions – 36”



MILLIKEN INFRASTRUCTURE
A Milliken COMPANY

Source – NASST No DIG 2016, Dallas TX – Paper No WM-T6-03 (Royer & Allouche)

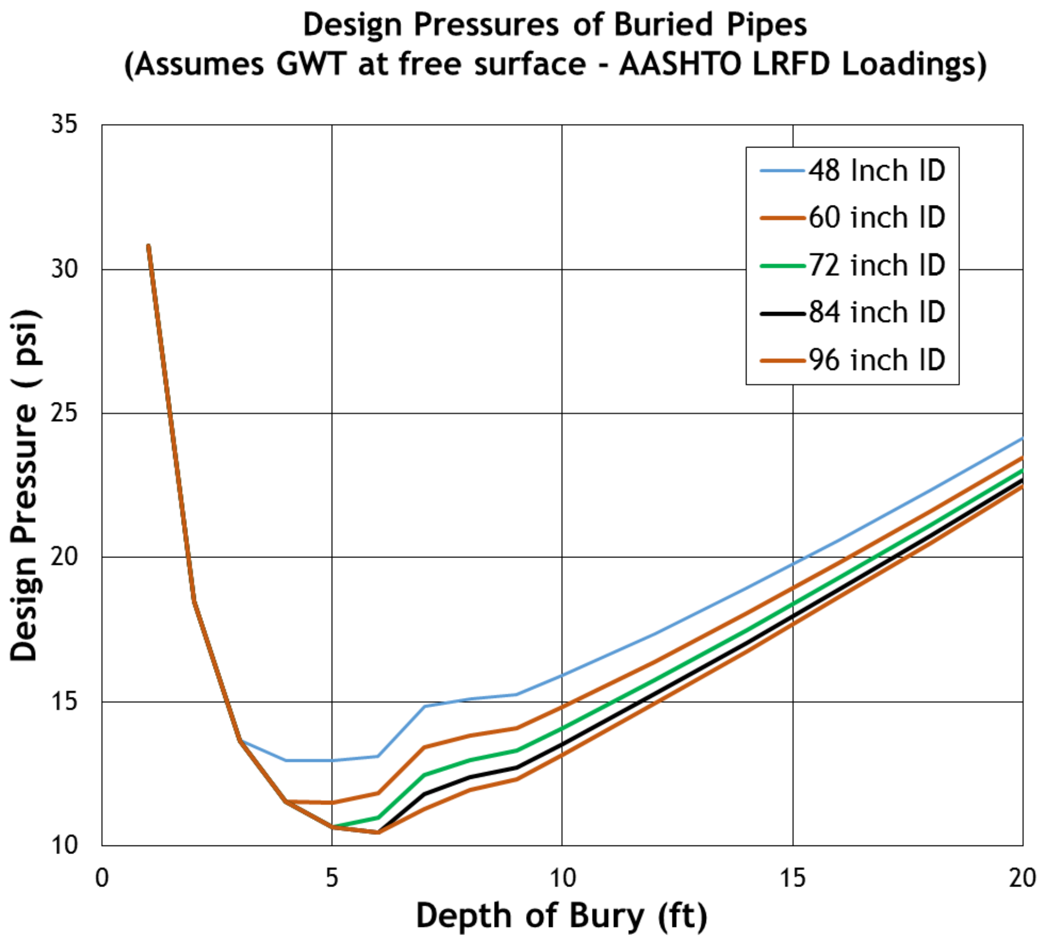
La Tech – TTC: Data Comparison to Model Predictions – 48”



MILLIKEN INFRASTRUCTURE
A Milliken COMPANY

Source – NASST No DIG 2016, Dallas TX – Paper No WM-T6-03 (Royer & Allouche)

La Tech – TTC: Real World Field Conditions



MILLIKEN INFRASTRUCTURE
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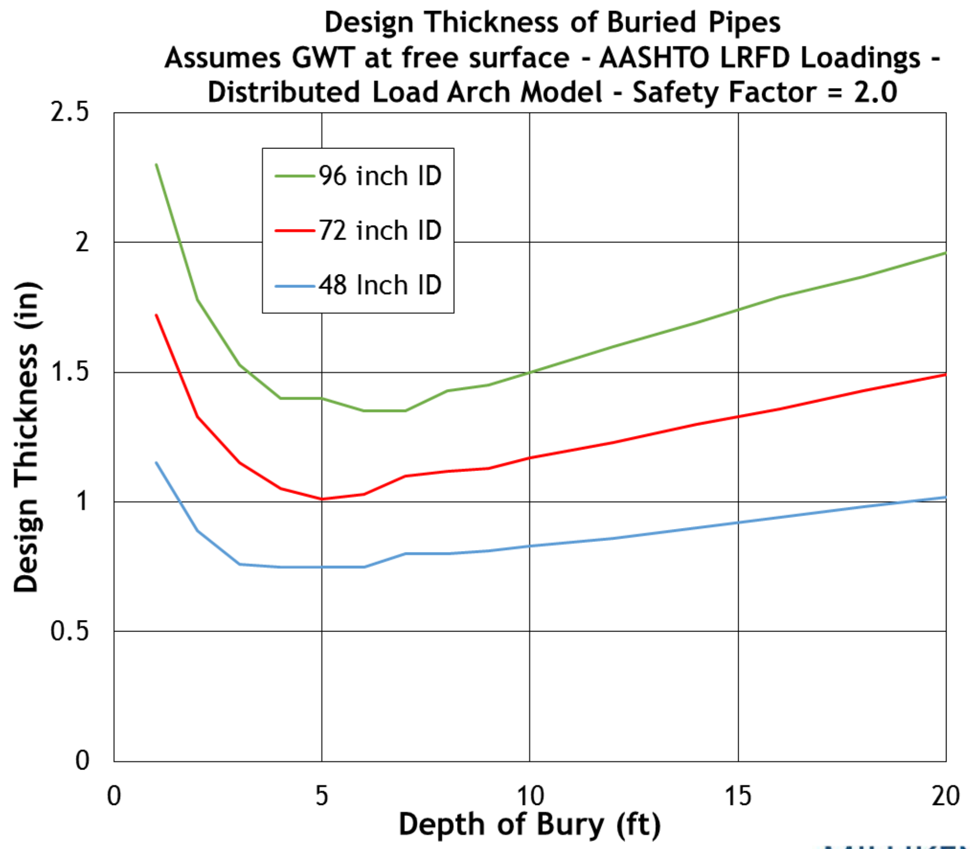
Source – NASST No DIG 2016, Dallas TX – Paper No WM-T6-03 (Royer & Allouche)

La Tech – TTC: Liner Thickness – Beam Load Model

This model give good representation of the data and is more conservative as pipe size increase under typical loads



MILLIKEN INFRASTRUCTURE
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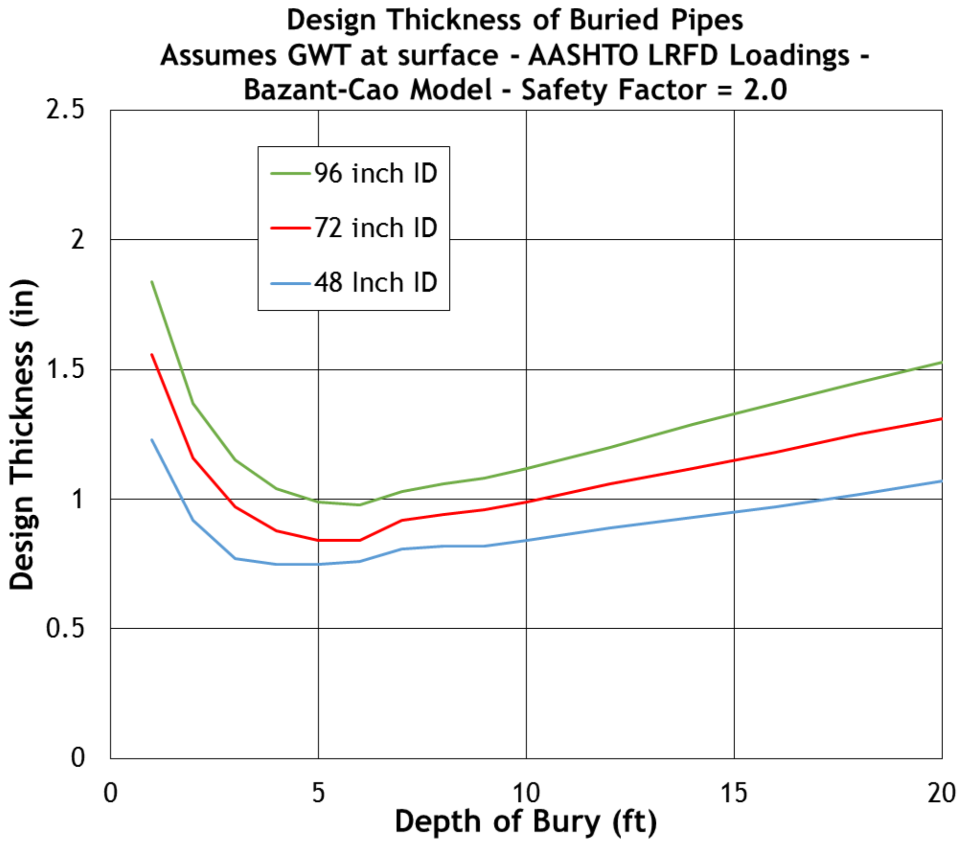
Source – NASST No DIG 2016, Dallas TX – Paper No WM-T6-03 (Royer & Allouche)

La Tech – TTC: Liner Thickness – Bazant-Cao Model

This model is less conservative at typical field conditions a pipe diameter increases.



MILLIKEN INFRASTRUCTURE
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Source – NASST No DIG 2016, Dallas TX – Paper No WM-T6-03 (Royer & Allouche)

La Tech – TTC: Conclusions

- 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).

Source – NASST No DIG 2016, Dallas TX – Paper No WM-T6-03 (Royer & Allouche)

First Name	Last Name	Title	Email	Phone	Present
Darby	Clayton		darby.j.clayton@wv.gov	304-558-9567	1
Kean	Ashurst		kean.ashurst@uky.edu	859-257-7319	1
Doug	Gesso		doug.gesso@ky.gov	502-782-4881	1
Katheryn	Malusky		kmalusky@aashto.org	202-624-3695	1
Kyle	Larson		klarson@ksdot.org	785-291-3825	1
Robert	Meinzer		bmeinzer@conteches.com		1
David	Keaffaber	Midwest Region Manager	david.keaffaber@milliken.com	317-306-6595	1
Maribel	Wong		mwong@aashto.org	202-624-3559	1
Natalie	Roskam	Ncdot	nroskam@ncdot.gov		1
Vince	Glick		vglick@aashto.org	202-624-7743	1
Brennan	Roney		broney@dot.ga.gov	404-608-4816	1
David	Kotzer		david.kotzer@state.co.us	303-398-6566	1
Sabra	Gilbert-Young		sgilbert-young@dot.state.nv.us	775-888-7894	1
Jack	Cowsert		jcowsert@ncdot.gov	919-329-4030	1
Ting	Nahrwold		tnahrwold@indot.in.gov	317-232-5080	1
John	Rublein		john.rublein@dot.wi.gov	608-246-7953	1
Guohua	Lian		glian@dot.ga.gov	404-608-4824	1
Chip	Johnson		cjohnson@sprayroq.com		1
Kidada	Dixon		dixonk@dot.state.al.us	334-353-6940	1
John	Schuler		john.schuler@vdot.virginia.gov	804-328-3140	1
Rodney	Klopp		rklopp@pa.gov	717-787-7827	1
Andy	Bennett		bennetta@michigan.gov	517-322-5043	1
Allen	Gallistel		allen.gallistel@state.mn.us	651-366-5545	1
Karen	Byram		karen.byram@dot.state.fl.us	850-414-4353	1
Mike	Paipal	Field Engineer	paipalm@fivestarproducts.com		1
Jeffrey	Syar		jeffrey.syar@dot.ohio.gov	614-275-1373	1
Rodrigo	Herrera		rodrigo.herrera@dot.state.fl.us	850-414-4377	1
Richard	Douds		rdouds@dot.ga.gov	404-608-4805	1
Douglas	Gayne		doug.gayne@maine.gov	207-624-3268	1
Mario	Paredes	Senior Research Engineer	mparedes@tri-env.com	352-231-0992	1
Therese	Kline		klinet@michigan.gov	517-241-0082	1