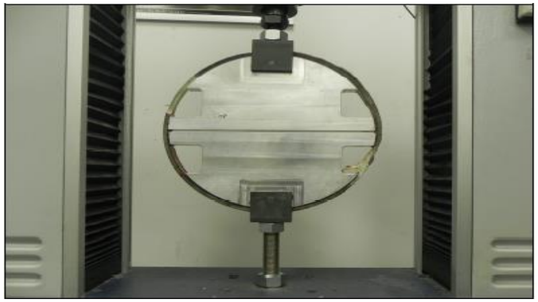
Watermain Renovation Using Structural, Semi-Structural and Non-Structural Lining Systems



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January 31, 2018
New Orleans, LA

- **Pressure pipe rehabilitation continues to expand in acceptance and implementation around the world**
  - $1 *trillion* dollars to be invested in water main rehabilitation in North America over the next 25 years
  - AWWA Manual M28 will continue to evolve and will relied upon to play a major role for Guidance in Rehabilitation Programs
- **There is considerable misunderstanding as to what M28 does and doesn’t provide in terms of direction on rehabilitation design**
  - This is a global issue when it comes to structural design standards
  - Many concepts are currently advanced in a qualitative manner as opposed to quantitatively
  - This can lead to inconsistencies when trying to rationalize equivalent solutions

What is in AWWA M28?

- Problem definitions
- Technology overview
- Matching problems to technology
- Planning and delivery considerations
  - Logistical Considerations (maintaining service and communications issues)
  - Overall Programing
- Common approaches to pipe prep for lining technologies
- Qualitative overview of Structural Lining

ISO AWWA
Class A = IV
Class B = III
Class C = II
Class D = I

Structural Classifications Standardization – ISO vs AWWA

- In ISO 11295, subcommittee TC138/SC8 "Rehabilitation of Pipeline Systems" has published structural classifications for pressure pipe liners which are closely aligned with those of AWWA Manual M28
  - Class D (non-structural) through Class A (fully structural) as opposed to Class I through IV
  - Similar qualitative measures
- In NA, the AWWA sub-committee on *"Structural Classifications of Lining Systems"* has similarly been working on a ***Suggested Protocol for Structural Product Classification***

Liner characteristics	Class A	Class B	Class C	Class D
Can survive internally or externally induced (burst, bending or shear) failure of host pipe	✓	—	—	—
Long-term pressure rating ⩾ maximum allowable operating pressure (MAOP)	✓	—	—	—
Inherent ring stiffness[a]	✓	✓	—[b]	—[b]
Long-term hole and gap spanning at MAOP	✓	✓[c]	✓	—
Provides internal barrier layer[d]	✓	✓	✓	✓

[a] The minimum requirement is for the liner to be self-supporting when pipe is depressurized.

[b] The liner relies on adhesion to the host pipe to be self-supporting when depressurized.

[c] The liner becomes sufficiently close-fit for radial transfer of internal pressure stress to the host pipe, either during installation or within a short period from initial application of operating pressure.

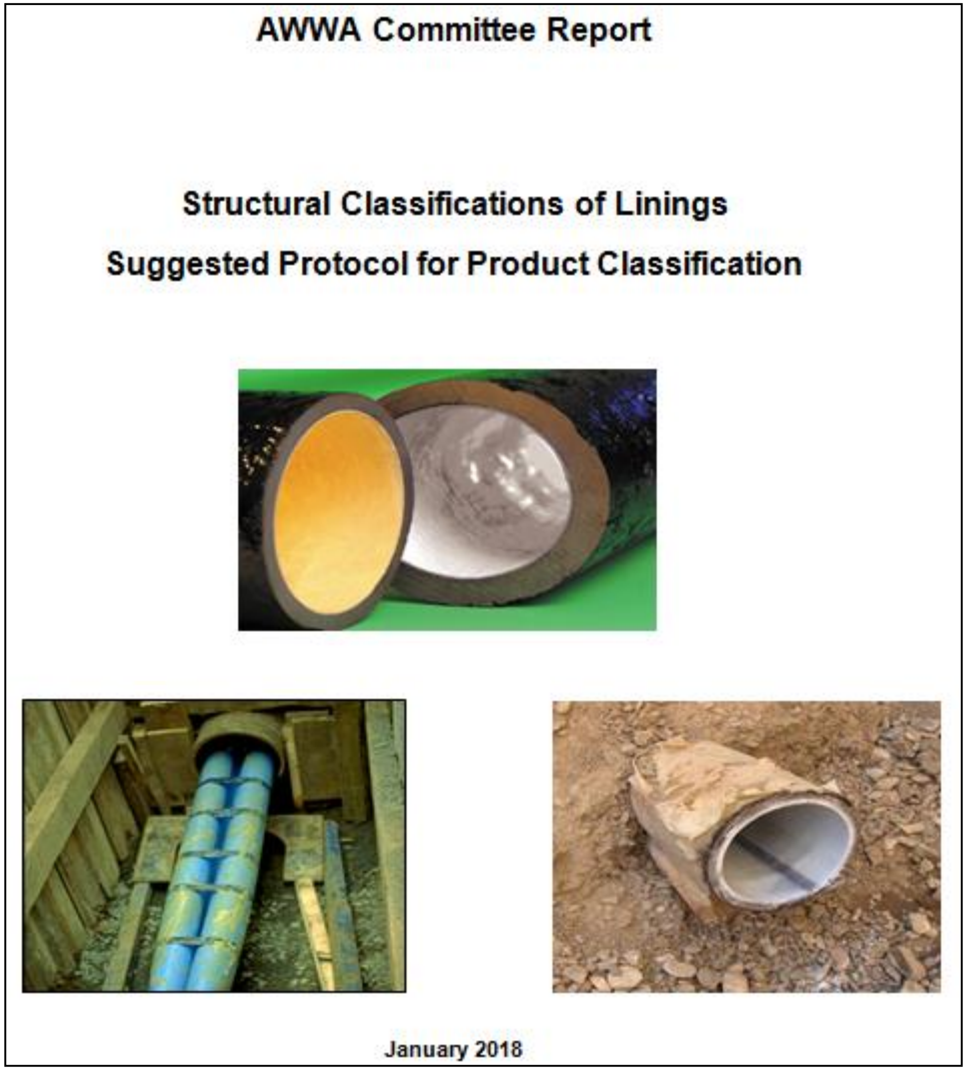
[d] The liner serves as barrier to the corrosion, abrasion and/or tuberculation/scaling of the host pipe and to the contamination of the pipe contents by the host pipe; it also generally reduces surface roughness for improved flow capacity.

ISO Structural Classifications

LINER CHARACTERISTICS	NON-STRUCTURAL	SEMI-STRUCTURAL		FULLY STRUCTURAL
	CLASS I	CLASS II	CLASS III	CLASS IV
INTERNAL CORROSION BARRIER	YES	YES	YES	YES
BRIDGES HOLES/GAPS AT PIPE OPERATING PRESSURE	NO	YES	YES	YES
INHERENT RING STIFFNESS	NO (depends on adhesion)	NO (depends on adhesion)	YES*	YES*
LONG-TERM INDEPENDENT PRESSURE RATING ≥ PIPE OPERATING PRESSURE	NO	NO	NO	YES
SURVIVES "BURST" FAILURE OF HOST PIPE	NO	NO	NO	YES

AWWA Structural Classifications

- Structural Classification of Linings – Suggested Protocol for Product Classification
  - Takes qualitative concepts to a quantitative format
  - Provides guidance on design and product selection for all lining products
  - Provides illustrative examples of sound engineering judgement to go beyond current design code



AWWA Committee Report

Structural Classifications of Linings

Suggested Protocol for Product Classification

January 2018

Some Practical Aspects of the AWWA Structural Classifications Framework

- **Alignment of Lining Application Requirements with an Owner's Design Objectives**
  - When is a Class IV (or any other Class) liner really a Class IV liner???
  - Need to match products to Owner's Design Objectives
  - Owner's design objectives many be similar but often vary considerably

- **How Do We Do This?**

  A. *Problem Definition Statements* – The Owner/Engineer needs to quantify failure applied loads and design condition

  B. *Type Tests* – the products need quantifiable measures of short and long term mechanical/chemical resistance properties

  C. *Acceptance Tests* – How we measure in the field that we met the design objectives

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Taking Qualitative Concepts to Quantitative Measures

- How does your product achieve the qualitative objective for each liner class?
- Provides insight to what tests are relevant to achieve this

LINER CHARACTERISTICS	NON-STRUCTURAL	SEMI-STRUCTURAL		FULLY STRUCTURAL
	CLASS I	CLASS II	CLASS III	CLASS IV
INTERNAL CORROSION BARRIER	YES	YES	YES	YES
BRIDGES HOLES/GAPS AT PIPE OPERATING PRESSURE	NO	YES	YES	YES
INHERENT RING STIFFNESS	NO (depends on adhesion)	NO (depends on adhesion)	YES*	YES*
LONG-TERM INDEPENDENT PRESSURE RATING ≥ PIPE OPERATING PRESSURE	NO	NO	NO	YES
SURVIVES "BURST" FAILURE OF HOST PIPE	NO	NO	NO	YES

Water tight lining? Close fit? Adhesion to host pipe?

Close fit? Adhesion? Long Term Flexural Strength? In what direction?

Close fit? Long Term Flexural Modulus?

Long Term Hydrostatic Strength?

Is localized or continuous adhesion involved? For all failure modes?

Build the Roadmap with Quantifiable Objectives

- What testing regimen would this logically lead to?
- What issues remain unresolved?

LINER CHARACTERISTICS	NON-STRUCTURAL	SEMI-STRUCTURAL		FULLY STRUCTURAL
	CLASS I	CLASS II	CLASS III	CLASS IV
INTERNAL CORROSION BARRIER	YES	YES	YES	YES
BRIDGES HOLES/GAPS AT PIPE OPERATING PRESSURE	NO	YES	YES	YES
INHERENT RING STIFFNESS	NO (depends on adhesion)	NO (depends on adhesion)	YES*	YES*
LONG-TERM INDEPENDENT PRESSURE RATING ≥ PIPE OPERATING PRESSURE	NO	NO	NO	YES
SURVIVES "BURST" FAILURE OF HOST PIPE	NO	NO	NO	YES

Hydrostatic leakage test; visuals; ASTM D4541/ISO 4624

visuals; ASTM D4541/ISO 4624; Long Term Flexural Strength

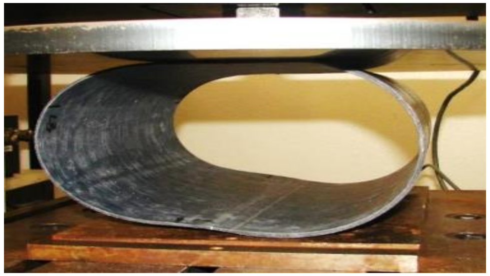
Visual; Long term Flexural modulus properties

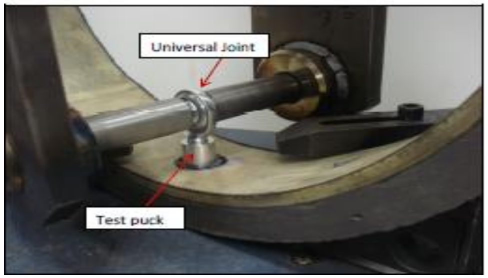
ASTM D2992 – HDB Testing;
ISO 7509/10928
ASTM D2990 – Tensile Creep
Short term and reduction? Basis for same?

Do I still have a Class IV Liner; have I incorporated the host pipe in the solution? Do I know enough about their interaction? Fracture tests; manageable risk?

Where We Are – AWWA Testing Objectives

- ISO's product testing standard ISO 11297-4 / 11298-4 (CIPP for pressure sewers and WM's) has brought a number of practical implications of current liner structural classifications into sharper focus.
- We face the same practical issues:
  - Design, test approaches, pending long term test results, and
  - *The demand to keep working while working to achieve consensus on a number of complex issues for a wide variety of products*
- Core objectives for both committees:
  - Common, objective and verifiable criteria based on sound engineering principles
  - Assessing ***"fitness for purpose"*** of pressure lining products for different clearly defined applications.





Design Challenges

- Some of the most challenging issues ahead include:
  - ***Long Term Testing***
    - Hydrostatic strength (hoop direction)
    - Flexural strength (in all directions)
  - ***Design***
    - Having relevant design methods for radically different and evolving products
  - ***Acceptance Tests***
    - Carrying out meaningful tests post installation to reasonably confirm design intent has been achieved

Design Methodology

- ASTM F1216 first introduced in 1989
- To date most pressure liners in North America have used Appendix X1 of ASTM F1216 as the design basis for liners
- With provision for gravity and pressure pipe loading applications, it provides a design approach for un-bonded close fit liners with checks for:
  - **Gravity flow pipelines**
    - Buckling due to hydrostatic loads limited by stiffness (modified Timoshenko)
    - Hydrostatic loads limited by flexural strength
    - Buckling loads due to earth/live loads (modified from Luscher)
  - **Pressure pipe**
    - Hole spanning (interactive design)
    - Full hoop stress (independent design)
  - Standard has a minimum stiffness requirement (Equation X.1.4)

Designation: F 1216 – 09

An American National Standard

Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube[1, 2]

This standard is issued under the fixed designation F 1216; 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.

APPENDIXES

(Nonmandatory Information)

X1. DESIGN CONSIDERATIONS

X1.1 *Terminology*:

X1.1.1 *partially deteriorated pipe*—the original pipe can support the soil and surcharge loads throughout the design life of the rehabilitated pipe. The soil adjacent to the existing pipe must provide adequate side support. The pipe may have longitudinal cracks and up to 10.0% distortion of the diameter. If the distortion of the diameter is greater than 10.0%, alternative design methods are required (see Note 1).

X1.1.2 *fully deteriorated pipe*—the original pipe is not structurally sound and cannot support soil and live loads or is expected to reach this condition over the design life of the rehabilitated pipe. This condition is evident when sections of the original pipe are missing, the pipe has lost its original shape, or the pipe has corroded due to the effects of the fluid, atmosphere, soil, or applied loads.

X1.2 *Gravity Pipe*:

X1.2.1 *Partially Deteriorated Gravity Pipe Condition*—The CIPP is designed to support the hydraulic loads due to groundwater, since the soil and surcharge loads can be supported by the original pipe. The groundwater level should be determined by the purchaser and the thickness of the CIPP should be sufficient to withstand this hydrostatic pressure without collapsing. The following equation may be used to determine the

$$P = \frac{2KE_L}{(1-\nu^2)} \cdot \frac{1}{(DR-1)^3} \cdot \frac{C}{N} \qquad \text{(X1.1)}$$

where:

P = groundwater load, psi (MPa), measured from the invert of the pipe

K = enhancement factor of the soil and existing pipe adjacent to the new pipe (a minimum value of 7.0 is recommended where there is full support of the existing pipe),

E_L = long-term (time corrected) modulus of elasticity for CIPP, psi (MPa) (see Note X1.1),

ν = Poisson's ratio (0.3 average),

DR = dimension ratio of CIPP,

C = ovality reduction factor =

$$\left(\left[1-\frac{\Delta}{100}\right] / \left[1+\frac{\Delta}{100}\right]^2\right)^3$$

Δ = percentage ovality of original pipe =

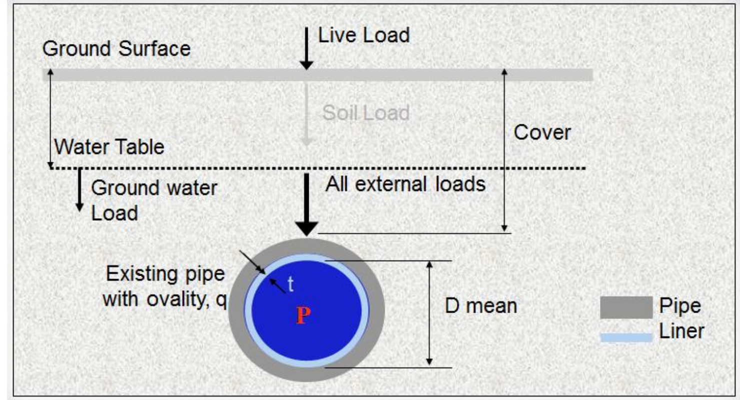
$$100 \times \frac{(Mean\ Inside\ Diameter - Minimum\ Inside\ Diameter)}{Mean\ Inside\ Diameter}$$

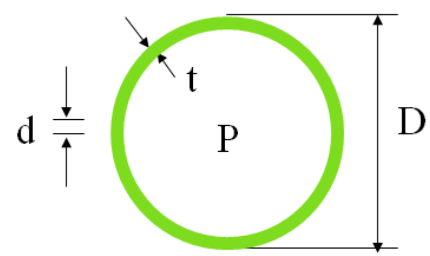
$$\frac{EI}{D^3} = \frac{E}{12(DR)^3} \geq 0.093\ (inch-pound\ units), \qquad \text{(X1.4)}$$

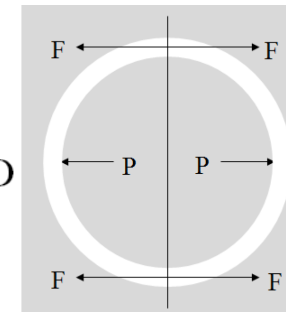
$$\frac{E}{12(DR)^3} \geq 0.00064\ (SI\ units)$$

Design Methodology

- ***ASTM F1216 has it all, you say? Why do we need more?***
- Design methods need to reasonably match the products that they are intended for
  - It's seldom a perfect fit
  - But you need to assess the relevance of the design method to the products
- While F1216 has served the industry well, it's evolution was based on:
  - Un-bonded liners
  - Non-reinforced tubes, or at least
    - ***Isotropic liner material*** behavior
  - Compromises, consensus, and many other things that are a reality of standards
    - Minimum stiffness for flexibility for a close fit liner doesn't make sense
- There is another design standard in Draft Form - AWWA Manual for ***CFRP RENEWAL AND STRENGTHENING OF PCCP***







CFRP Design Approach

Zarghamee

- Consider degradation level of host pipe
- Stand-alone versus composite design (with inner core)
- Use LRFD

Circumferential Design

Limit State	Loads
CFRP Rupture	Internal pressure + External gravity loads
Buckling	External loads - Groundwater + Vacuum
Debonding	Empty pipe under external loads

Longitudinal Design

Limit State	Loads
CFRP Rupture	Internal pressure (Thrust, Poisson) + Temperature
Debonding	Internal pressure (Thrust, Poisson) + Temperature
Buckling	Temperature

AECOM

ASTM F1216 vs. AWWA PCCP Draft Design Inherent Design Differences

Design Checks	ASTM F1216	AWWA PCCP Draft
Hoop Design		
- Working Pressure	X	X
- Transient Pressure		X
- Vacuum Pressure		X
- Traffic Loads	X	X
- Soil Loads	X	X
- Ovality	X	X
- Deflection Limits		X
- Combined Loading		X
Longitudinal Design		
- Poisson's Effect		X
- Temperature Effect		X
- Thrust Effect		X

Design Example

Design Conditions:

AWWA M28 Structural Classification		Class IV
Host pipe diameter	$D =$	12.00 in
Host pipe material		Cast Iron
Host pipe type (rigid or flexible)		Rigid
Hole diameter (from future external corrosion)	$d =$	1.00 in
Design factor of safety	$N =$	2.0
Burial depth	$H =$	5.0 ft
Groundwater depth (from top of pipe)	$H_W =$	1.0 ft
Internal working pressure	$P_W =$	100 psi
Surge pressure	$P_S =$	50 psi
Test pressure	$P_T =$	150 psi
Constrained soil modulus	$M_{sn} =$	3,000 psi
Vacuum	$P_V =$	14.7 psi
Unit weight of soil overburden	$\gamma_S =$	120 lb/ft^3
Unit weight of water	$\gamma_W =$	62.4 lb/ft^3
Enhancement factor	$K =$	7.0
Host pipe ovality	$q =$	0.10 %
Surface live load		HS-20
Cooper E80 design condition (if applicable)		N/A
Temperature change	$\Delta T =$	0 °F
Installation length	$L =$	300 ft
Will the pipeline be out of service for an extended time?		No

Design Example

Lining System Characteristics:

Initial flexural modulus (hoop)	E_{FHS} =	300,000	psi
Initial flexural strength (hoop)	σ_{FHS} =	10,000	psi
Initial flexural modulus (axial)	E_{FAS} =	300,000	psi
Initial flexural strength (axial)	σ_{FAS} =	5,000	psi
Long-term retention of flexural properties		50%	
Long-term flexural modulus (hoop)	E_{FHL} =	150,000	psi
Long-term flexural strength (hoop)	σ_{FHL} =	5,000	psi
Long-term flexural modulus (axial)	E_{FAL} =	150,000	psi
Long-term flexural strength (axial)	σ_{FAL} =	2,500	psi
Tensile modulus (hoop)	E_{TH} =	1,000,000	psi
Initial tensile strength (hoop)	σ_{THS} =	12,000	psi
Tensile modulus (axial)	E_{TA} =	500,000	psi
Initial tensile strength (axial)	σ_{TAS} =	6,000	psi
Long-term retention of tensile properties		50%	
Long-term tensile strength (hoop)	σ_{THL} =	6,000	psi
Long-term tensile strength (axial)	σ_{TAL} =	3,000	psi
Compression modulus (axial)		300,000	psi
Coefficient of thermal expansion/contraction	α =	0.00005	in/in/°F
Poisson's Ratio of lining system	υ =	0.30	
Hydrostatic design basis - stress basis (psi)	HDB_{σ} =	N/A	psi
Hydrostatic design basis - strain basis (in/in)	HDB_{ε} =	0.0065	in/in
Short-term burst pressure (ASTM D1599)	P_B =	600	psi
Pressure rating factor (straight alignment)	PRF_S =	4.0	
Pressure rating factor (through bends)	PRF_B =	5.0	
Adhesion strength of liner to host pipe substrate	σ_{ad} =	1,000	psi

Class I and Class II Checks

Class I Design Checks:

If negative pressures exist, the lining system must provide reliable adhesion to the host pipe

Adhesion check:	$P_N \cdot N + \alpha \cdot E_{FHS} \cdot \Delta T$ =	31.1 psi	Must satisfy: $\sigma_{ad} \geq P_N \cdot N + \alpha \cdot E_{FHS} \cdot \Delta T$	**OK**
	P_N =	15.6 psi	$P_N = \dfrac{\gamma_W \cdot (H_W + D/12)}{144} + P_V$	
	t_1 =	**0.12 in**	Based on maximum DR = 100 for CIPP	

Class II Design Checks:

Class I design checks PLUS:

Hole span:	**t_{2a} =**	**0.12 in**	$t_{2a} = \dfrac{D}{\left[\left(\frac{D}{d}\right)^2 \left(\frac{5.33 \cdot \sigma_{FAL}}{P_W \cdot N}\right)\right]^{\frac{1}{2}} + 1}$	
	d/D =	0.083		
	1.83 x $(t_{2a}/D)^{1/2}$ =	0.184	Must satisfy: $\dfrac{d}{D} \leq 1.83 \cdot \left(\dfrac{t_{2a}}{D}\right)^{\frac{1}{2}}$	**OK**

Class III Design Checks

Class III Design Checks:

Class I and II design checks PLUS:

W_s = 2.56 psi — Live load at depth H

C = 0.99 — Ovality reduction factor = $\left(\frac{1-q/100}{[1+q/100]^2}\right)^3$

External buckling resistance (short-term):

Rigid host pipe: **t_{3a} = 0.22 in**

$$t_{3a}=\frac{D}{\left(\left[\frac{2\cdot K\cdot E_{FHS}\cdot C}{(1-\upsilon^2)\cdot N\cdot P_N}\right]^{1/3}\right)+1}$$

Flexible host pipe: **t_{3a} = - in**

$$t_{3a}=\frac{D}{\left(\left[\frac{2\cdot K\cdot E_{FHS}\cdot C}{(1-\upsilon^2)\cdot N\cdot (P_N+W_s/2)}\right]^{1/3}\right)+1}$$

External buckling resistance (long-term):

This applies to pipelines that are out of service for an extended period of time: **t_{3b} = - in**

$$t_{3b}=\frac{D}{\left(\left[\frac{2\cdot K\cdot E_{FHL}\cdot C}{(1-\upsilon^2)\cdot N\cdot P_N}\right]^{1/3}\right)+1}$$

Class IV Design Checks – Phase 1 Sustained (Static) Pressure

Class IV Design Checks:

Class I, II and III design checks PLUS:

Internal pressure resistance, MAOP (static pressure, long-term):

Stress basis

Long-term tensile):	**t_{4a} =**	**0.20 in**	$$t_{4a} = \frac{D}{\left(\frac{2 \cdot \sigma_{THL}}{P_W \cdot N}\right) + 1}$$
HDB stress basis (if applicable):	**t_{4a} =**	**- in**	$$t_{4a} = \frac{D}{\left(\frac{2 \cdot HDB_{\sigma}}{P_W \cdot N}\right) + 1}$$

Strain basis

HDB strain basis:	**t_{4b} =**	**0.18 in**	$$t_{4b} = \frac{D}{\left(\frac{2 \cdot HDB_{\varepsilon} \cdot E_{TH}}{P_W \cdot N}\right) + 1}$$

Class IV Design Checks – Phase 2
Short Term Over-Pressure (Surge)

Internal pressure resistance, MAP = MAOP + surge (long-term):

Stress basis

Long-term tensile:	t_{4c} =	**0.21 in**	$t_{4c} = \dfrac{D}{\left[\dfrac{2.8 \cdot \sigma_{THL}}{(P_W + P_S) \cdot N}\right] + 1}$
HDB stress basis (if applicable):	t_{4c} =	**- in**	$t_{4c} = \dfrac{D}{\left[\dfrac{2.8 \cdot HDB_{\sigma}}{(P_W + P_S) \cdot N}\right] + 1}$

Strain basis

HDB strain basis:	t_{4d} =	**0.19 in**	$t_{4d} = \dfrac{D}{\left[\dfrac{2.8 \cdot HDB_{\epsilon} \cdot E_{TH}}{(P_W + P_S) \cdot N}\right] + 1}$

Class IV Design Checks – Phase 3 External Loads

Total External Load (Soil, Hydraulic, Live Loads):

This applies to pipelines that are out of service for an extended period of time, or if $q_t > P_W$

q_t =	6.89 psi	$q_t = 0.433 \cdot H_W + \frac{\gamma_S \cdot H \cdot R_W}{144} + W_S$
R_W =	0.93	Water buoyancy factor = 1 - 0.33(H_w/H) (≥ 0.67)
B' =	0.20	Coefficient of elastic support =$1/(1+4e^{-0.065H})$
t_{4e} =	**- in**	$t_{4c} = \left[\frac{(q_t \cdot N)^2 \cdot D^3 \cdot 12}{32 \cdot R_W \cdot B' \cdot M_{sn} \cdot E_{FHL} \cdot C}\right]^{1/3}$

1. Modified Luscher Buckling? (full overburden – no host pipe)
2. Timoshenko or Glock Models? (host pipe has inherent ring strength over time)
3. How long will your pipe really be out of service? 1000 hr or 50 year modulus

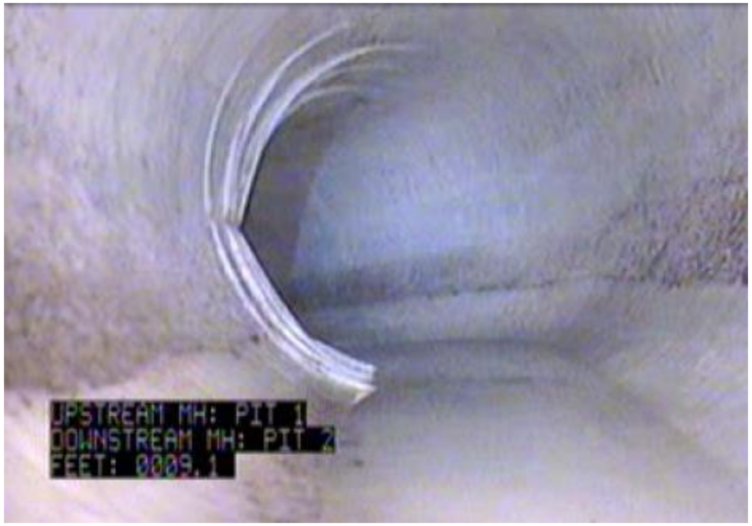
Class IV Design Checks – Phase 4 Alignment Modifications

Check working pressure:

For host pipe in straight alignment:	P_B/PRF_S =	150 psi	Must satisfy:	$P_w \leq \frac{P_B}{PRF_S}$	**OK**
When lining through bends:	P_B/PRF_B =	120 psi	Must satisfy:	$P_w \leq \frac{P_B}{PRF_B}$	**OK**

Check surge pressure:

For host pipe in straight alignment:	$(P_W + P_S)/1.4$ =	107 psi	Must satisfy:	$\frac{P_w + P_s}{1.4} \leq \frac{P_B}{PRF_S}$	**OK**
When lining through bends:			Must satisfy:	$\frac{P_w + P_s}{1.4} \leq \frac{P_B}{PRF_B}$	**OK**



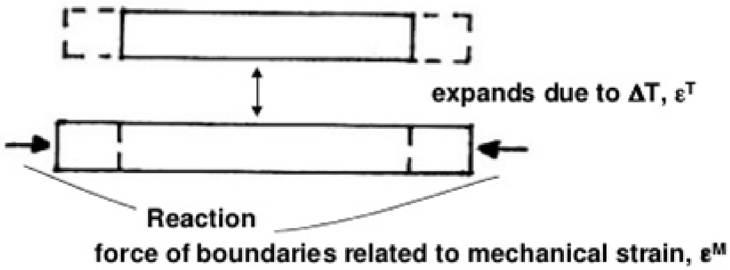
Class IV Design Checks – Phase 5 Axial Loads – Thermal

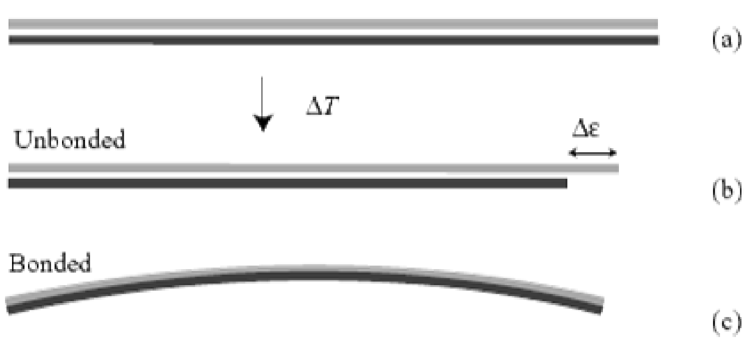
Thermal effects:

Length change due to temperature change (if liner is not adhered to host pipe): L_C = 0 in $L_C = 12 \cdot \alpha \cdot L \cdot \Delta T$

If ends are anchored: $\alpha \cdot E_A \cdot \Delta T$ = - psi Must satisfy: $\sigma_A \geq \alpha \cdot E_A \cdot \Delta T$ **OK**

- Thermal Expansion Effect

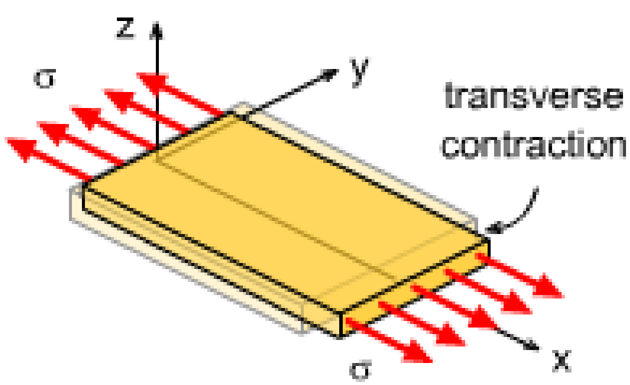


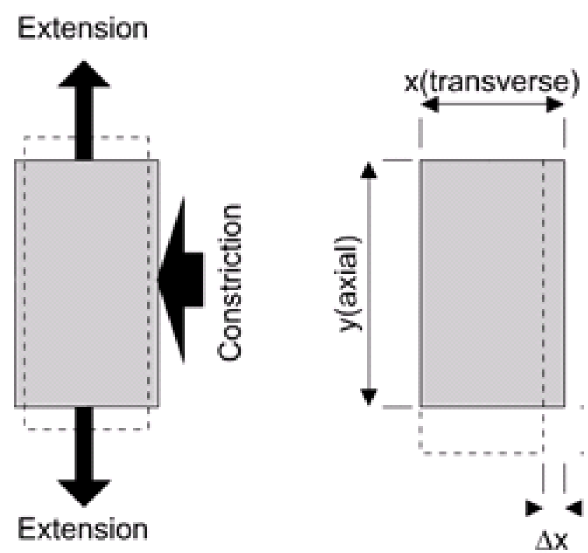


Class IV Design Checks – Phase 6
Poisson's Effect

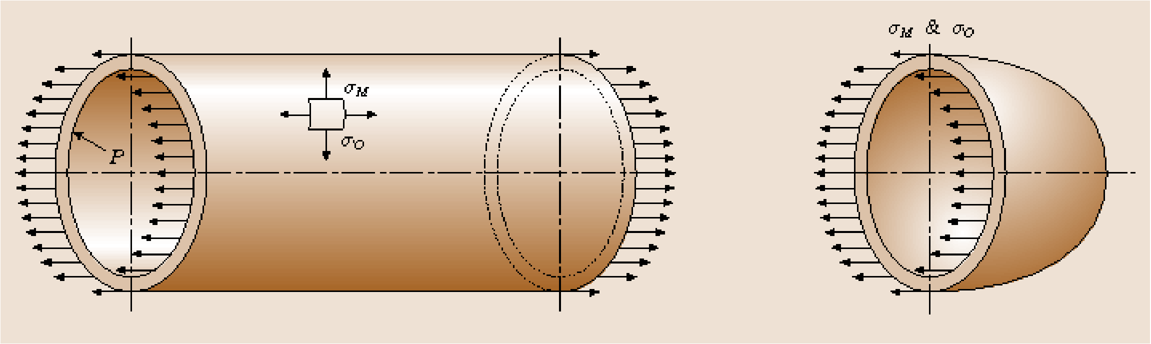
Poisson's Effect:

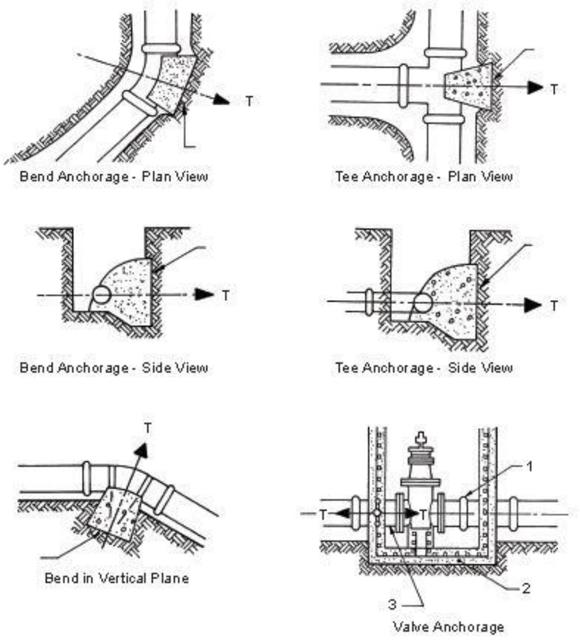
Maximum internal pressure:	P_P =	150 psi	P_P = greatest of P_W, (P_W + P_S) and P_T
Hoop stress:	σ_P =	3,957 psi	$\sigma_P = \frac{P_P \cdot (DR - 1)}{2}$
Dimension ratio of lining system:	DR =	54	DR = D/t_4
Pullout force due to Poisson's effect:	F_P =	9,804 lb	$F_P = \sigma_P \cdot \upsilon \cdot \pi \cdot D^2 \cdot \left[\frac{1}{DR} - \frac{1}{DR^2}\right]$





Class IV Design Checks – Phase 7
Axial Loads – Thrust?





Is the original thrust restraint adequate?
- If no, need to accommodate axial forces
- If yes, no check necessary
- Our Owner's problem statement indicated that thrust restraint was fine

Class IV Design Checks – Phase 7 Design Summary

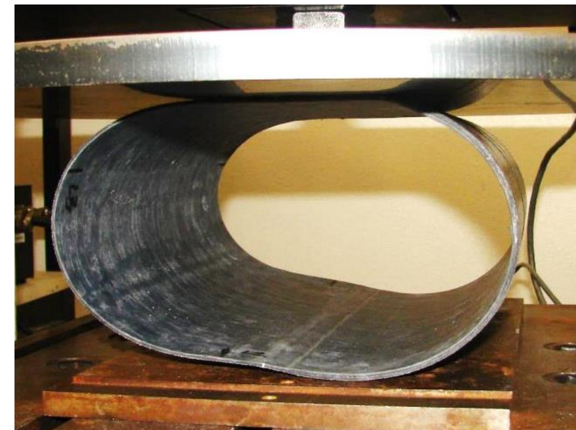
Design Summary:

Class I (Corrosion Barrier + Reliable Adhesion)	t_1 =	0.12 in	- in	Class I design thickness
	=	3 mm	- mm	
Class II (Class I + Hole Span)	t_2 =	0.12 in	- in	Greatest of all Class I & II design thicknesses
	=	3 mm	- mm	
Class III (Class I-II + Ring Stiffness)	t_3 =	0.22 in	- in	Greatest of all Class I, II & III design thicknesses
	=	5.67 mm	- mm	
Class IV (Class I-III + Internal and External Pressures)	t_4 =	0.22 in		Greatest of all Class I, II, III & IV design thicknesses
	=	5.67 mm		
Dimension ratio	DR =	54		

What's driving design?
- Earth loads for 50 years with no water in pipe and not support from host pipe?
- Is that what we really think the design condition should be?

ASTM F1216 for New Products: Moving Forward

- **Triggers for design beyond F1216**
  - Anisotropic lining material
  - Bond with the host pipe inherent in the design
  - Wide variance in thermal regime
  - Use of strain limited materials
  - Significant exposure to non-steady state pressure regimes
  - Exposure to higher pressures (>700 kPa or 100 psi)
- **Full roadmap needed from design to product to installation and verification in installed state**
  - F1216 provides that roadmap for gravity or low pressure head installations with non-reinforced liners
  - When the product changes substantially, the roadmap needs to get updated

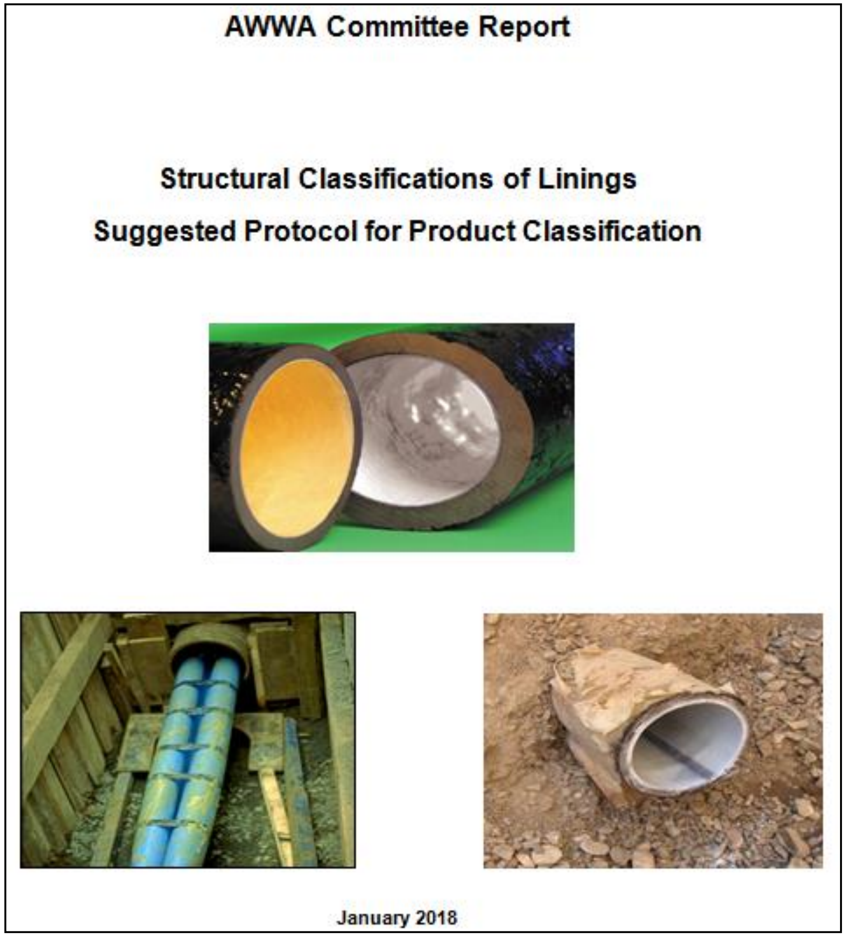


Moving Forward: Going Beyond Current Specifications

- Current Design Codes and Guidelines are based on the specific products that they were driven by
- Take the time to understand the specifics of the products you intend to use; their relevance and how they deviate from the Codes you are intending to use
  - Fully Understand the limitations of the code you are using
- Specify Appropriate Modifications to Extend Existing Codes to Match the Products you are using
  - Recognized, relevant tests that align with the design objectives
  - Use Sound Engineering Judgment to fill in the gaps
- Rationalize verification requirements for the construction phase

Conclusions

- AWWA M28 is currently an informational and guidance document
  - The guidance and qualitative objectives are good
- Need to move Pressure Liner requirements in AWWA M28 from ***qualitative to quantitative objectives***
  - *Objective and verifiable criteria based on sound engineering principles to assess "fitness for purpose" are primary objectives of current work*
  - ***That's what the Structural Classifications of Linings White Paper is intended to provide***
- It's a big world out there; pay attention to it and we'll get there quicker
- While the complete quantifiable roadmap is not there yet, there is plenty of quantifiable work done
  - Exercise sound engineering judgement for the jobs we are building now to increase clarity for tomorrow's jobs
  - Provide feedback on the White Paper and contribute to its growth from an Informational Document to the next generation of AWWA Standards


AWWA Committee Report

Structural Classifications of Linings

Suggested Protocol for Product Classification

January 2018

Questions?