CIPP LINER THICKNESS CHANGES UNDER F1216-07b

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ABSTRACT: The paper explains the changes to fully deteriorated design that came about with the release of ASTM F1216-07b in June 2007. In many cases, the change is significant in regard to how F1216-07b reduces liner thickness for the fully deteriorated pipe condition. The change, which relates to the ovality correction factor in F1216-07b design equation X1.3, means that the F1216 Appendix X1 design now yields thinner fully deteriorated liners in many situations. The paper will explain and discuss the exact change to Equation X1.3. It will also present a number of design examples that will illustrate what this change does to liner thickness. Examples will show pre and post F1216-07b liner thickness and how expectations regarding which F1216 equation governs liner thickness may no longer hold true. The paper will also look at whether the F1216-07b design change might result in changes to pricing and competitiveness due to thinner liners in many situations.

INTRODUCTION

In North America, the ASTM F1216 Appendix X1 design method is the industry standard procedure for calculating the wall thickness for CIPP (Cured-in-Place Pipe) liner thickness for sewers. The F1216 method is also widely used outside of North America. The F1216 design method has a section for gravity pipes (such as sewers) and a section for pressure pipes (such as sewer forcemains and watermains). While the F1216 liner design method applies only to circular pipes, it contains a provision, called Ovality, to account for nominally circular pipes that have gone out-of-round. For non-circular pipe shapes other designs methods are used, such as WRc Type II for egg-shaped sewers. The ASTM F1216 design method has a long history of successful application for CIPP sewer liners; its fundamentals have been adopted as a design method for other types of liners such as deformed polyethylene liners as presented in ASTM F1606.

The F1216 CIPP X1 Design Method was first published as ASTM F1216-89. Since then, the F1216 has been re-issued 9 times with F1216-91, 93, 98, 03, 05, 06, 07, 07a and 07b (June 2007). The full name of the document is *"Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube"*. All editions included the Appendix X1 Design Method. The revisions over the various editions have included revisions to Appendix X1. Until F1216-07b, all Appendix X1 design method revisions were for either clarification or editorial purposes and did not involve any changes to the design method itself that would result in different results for liner thickness. In F1216-07b, a significant change to one of the 4 design equations was introduced. This change can, and often does, result in significant reduction of CIPP liner thickness when the design requirement is for a fully deteriorated host pipe condition. The change was the relocation of the Ovality Correction Factor, C, in design equation X1.3. Before detailed discussion of the equation X1.3 change and its meaning to the CIPP field, the following overview of the F1216 design method for gravity pipes is presented.

OVERVIEW OF ASTM F1216 APPENDIX X1 DESIGN METHOD

The F1216 design method appendix has 3 parts: X1.1 Terminology, X1.2 Gravity Pipe and X1.3 Pressure Pipe. This paper does not discuss pressure pipe design. The Design Method recognizes 2 design approaches based on 2 conditions for the pipe to be lined which are either Partially Deteriorated or Fully Deteriorated. The Terminology section X1.1 provides definition of when the existing pipe should be considered either Partially or Fully deteriorated. In these definitions, both the present existing condition and the expected future condition throughout the design life of the lining are taken into account. While there is ongoing discussion in the industry whether a "Fully Deteriorated" condition can actually exist, it is not in the scope of this paper to engage that discussion. An ASCE Pamphlet on this topic is available at www.pipelinedivision.org. The partially and fully deteriorated conditions are de facto parameters of the F1216 Design Method and, as such, are part of the use of the Design Method.

For the Partially Deteriorated design condition, the F1216 design method requires satisfying 2 equations, X1.1 and X1.2. The required liner thickness is the highest thickness determined from satisfying the equations. The 2 equations are:

$$P = \frac{2KE_L}{(1 - v^2)} \cdot \frac{1}{(DR - 1)^3} \cdot \frac{C}{N} \qquad \text{[F1216 Equation X1.1]}$$

$$1.5 \, \frac{\Delta}{100} \left(1 + \frac{\Delta}{100}\right) DR^2 - 0.5 \left(1 + \frac{\Delta}{100}\right) DR = \frac{\sigma_L}{PN} \qquad \text{[F1216 Equation X1.2]}$$

For the Fully Deteriorated design condition, the F1216 design method requires satisfying 4 equations, X1.1, X1.2, X1.3 and X1.4. The required liner thickness is the highest thickness determined from satisfying the equations. The 4 equations, including the revised form of X1.3, are:

$$P = \frac{2KE_L}{(1 - v^2)} \cdot \frac{1}{(DR - 1)^3} \cdot \frac{C}{N} \qquad \text{[F1216 Equation X1.1]}$$

$$1.5 \, \frac{\Delta}{100} \left(1 + \frac{\Delta}{100}\right) DR^2 - 0.5 \left(1 + \frac{\Delta}{100}\right) DR = \frac{\sigma_L}{PN} \qquad \text{[F1216 Equation X1.2]}$$

$$q_t = \frac{1}{N} [32 R_W B' E'_S \cdot C(E_L I/D^3)]^{1/2} \qquad \text{[F1216-07b Revised Equation X1.3]}$$

$$q_t = \frac{C}{N} [32 R_W B' E'_S (E_L I/D^3)]^{1/2} \qquad \text{[F1216 Old Equation X1.3]}$$

$$\frac{EI}{D^3} = \frac{E}{12(DR)^3} \geq 0.093 \qquad \text{[F1216 Equation X1.4]}$$

The F1216 Design Method states, in X1.2.2, *"The minimum CIPP design thickness for a fully deteriorated condition should also meet the requirements of Eq X1.1 and X1.2."* and therefore there are 4 equations for fully deteriorated. Under F1216-07b, equation X1.3 may no longer be the governing equation. Correspondingly it becomes necessary to check all 4 equations and not rely only on X1.3 and X1.4. The various parameters in the 4 equations are well defined in F1216 Appendix X1 and therefore will not be further detailed here. However, it is useful to examine the general approach taken in equations X1.1 and X1.3. In each of these equations, the CIPP liner's capacity to resist external load pressure is calculated for the liner thickness. That is, the solutions to X1.1 and X1.3 is liner external load pressure capacity <u>not</u> liner thickness.

In equation X1.1, the solution P is the groundwater pressure, at invert, that a liner of a given DR (Dimension Ratio) can resist. DR is liner outside diameter divided by liner thickness, (DR=D/t). The liner DR is an input to the equation with liner thickness implicit in the DR. Therefore, for a given liner thickness, equation X1.1 provides the liner's groundwater pressure capacity. Note that the result from equation X1.1 is liner groundwater pressure capacity, not liner thickness. In equation X1.3, the solution q_t is the total external pressure that a liner of a given I (Moment of Inertia) can resist. I is an engineering property

dependent on wall shape. For a CIPP solid wall liner, I = (thickness)^3 divided by 12, ($I = t^3/12$). The liner I is an input to the equation with liner thickness implicit in I. Therefore, for a given liner thickness, equation X1.3 provides the liner's total external pressure capacity. Note that the result from equation X1.3 is liner total external pressure capacity <u>not</u> liner thickness. In typical practice, the executed approach to F1216 liner design is to solve equations X1.1 and X1.3 for liner thickness, t. This uses external loads (either ground water pressure or total external pressure) as inputs instead of outputs. Nevertheless, the design protocol in the F1216 equations X1.1 and X1.3 is to calculate liner external load capacity pressures with liner thickness as a known input. The relevance of this discussion on the F1216's form for equations X1.1 and X1.3 may become apparent later in this paper.

THE CHANGE MADE IN F1216-07b

The change made in F1216-07b affects fully deteriorated design only. The change was made to the location of the ovality correction factor, C, in equation X1.3.

<u>Old Equation X1.3, Pre F1216-07b</u> $q_t = \dfrac{C}{N} [32R_W B'E'_s(E_L I/D^3)]^{1/2}$

<u>Revised Equation X1.3 in F1216-07b</u> $q_t = \dfrac{1}{N} [32R_W B'E'_s \cdot C(E_L I/D^3)]^{1/2}$

q_t is the total external pressure capacity for the liner. For ovality at 0%, the ovality correction factor, C, equals 1 and q_t is maximum. As pipe ovality increases, C drops below 1 thereby reducing liner's external pressure capacity. The relationship is show in Table 1 and Figure 1. At 5% ovality the capacities are 64% (by old X1.3) and 80% (by revised X1.3) of the maximum capacity at 0% ovality.

Table 1. Relative Total External Pressure Capacity versus Ovality

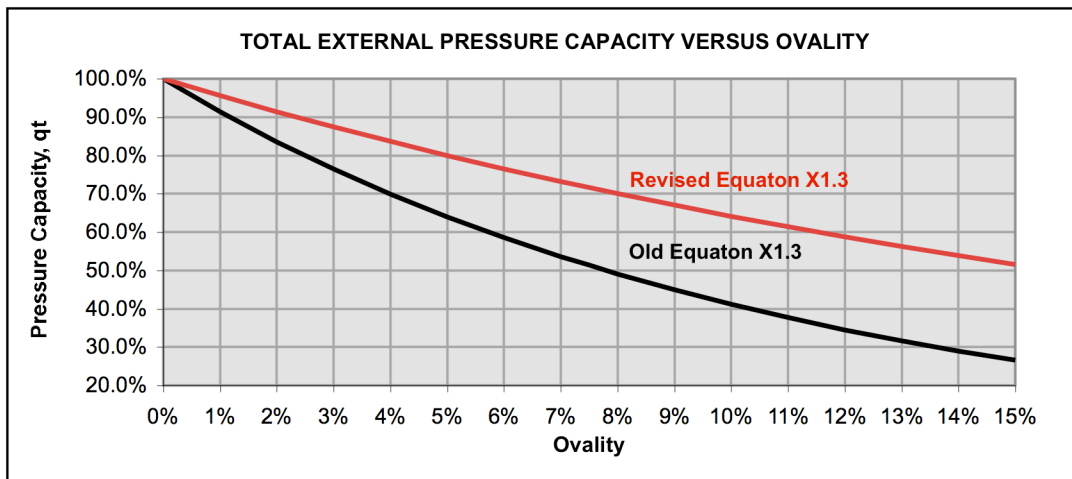| Pipe Ovality	C	Total External Pressure Capacity		Qt(new) / Qt(old)
		By Old X1.3	By Revised X1.3	
0.0%	1.000	100.0%	100.0%	1.000
1.0%	0.914	91.4%	95.6%	1.046
2.0%	0.836	83.6%	91.4%	1.094
3.0%	0.764	76.4%	87.4%	1.144
4.0%	0.699	69.9%	83.6%	1.196
5.0%	0.640	64.0%	80.0%	1.250
7.5%	0.513	51.3%	71.6%	1.396
10.0%	0.412	41.1%	64.1%	1.559
15.0%	0.266	26.6%	51.6%	1.939

Figure 1. Relative Total External Pressure Capacity versus Ovality

WHAT DOES THIS MEAN TO REQUIRED LINER THICKNESS?

Since in practical application, equation X1.3 is used to determine thickness for a given total external load pressure, it means that the liner thickness given by revised X1.3 is reduced. At 0% ovality there is no reduction. At 5% ovality the reduction is 13.8%. At 10% the reduction is 25.6%. Table 2 and Figure 2 provide illustration.

Table 2. Liner Thickness Reduction versus Ovality for F1216-07b Equation X1.3

Pipe Ovality	C	Reduction in Eq X1.3 Thickness by F1216-07b Compared to Previous F1216
0.0%	1.000	0.0%
1.0%	0.914	-3.0%
2.0%	0.836	-5.8%
3.0%	0.764	-8.6%
4.0%	0.699	-11.2%
5.0%	0.640	-13.8%
7.5%	0.513	-20.0%
10.0%	0.412	-25.6%
15.0%	0.266	-35.7%
Equation X1.3 only. Other F1216 equations may determine final liner thickness.		
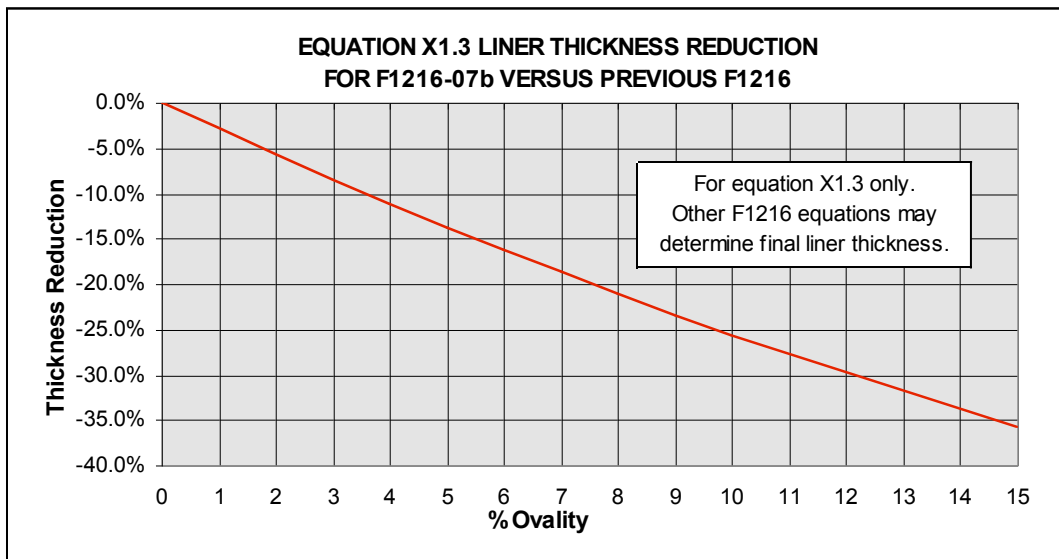
Figure 2. Liner Thickness Reduction versus Ovality for F1216-07b Equation X1.3

But – Not quite as straightforward as it appears above

Although in F1216-07b equation X1.3 changed to give reduced liner thicknesses, the other 3 equations did not change. It turns out that now equation X1.3 governs required liner thickness less often than before the change. Previously, it was very infrequent that X1.3 did not govern fully deteriorated liner thickness. With F1216-07b, there is increased probability that fully deteriorated thickness will be governed by one of the other 3 equations (X1.1, X1.2 or X1.4) not X1.3. As a result, fully deteriorated designs that consider only X1.3 now have an increased probability of being in error after the change in F1216-07b. Equation X1.3 is sometimes referred to as the AWWA equation or modified AWWA equation. Figures 3 to 9 are design examples comparing F1216-07b to previous F1216. Each example shows the thickness reduction and governing design equation. Preparation of the design example used the program CIPP-DESIGN.

EXAMPLE #1 (Fully Deteriorated Design)

Inside Diameter of Existing Pipe	8 ins	
Depth to Invert	8 ft	
Water Table Below Surface	4 ft	
Ovality	5%	
Soil Density	120 lb/ft3	
Soil Modulus	1,000 psi	
Live Load	HS-20	
Flexural Modulus short-term	300,000 psi	
Flexural Strength short-term	4,500 psi	
Long-term Retention	50%	

Existing Pipe Size 8 ins, Ovality 5.0%

Ground Surface / 4.00 ft / 7.33 ft / 8.00 ft / Water Table / 4.00 ft / Invert

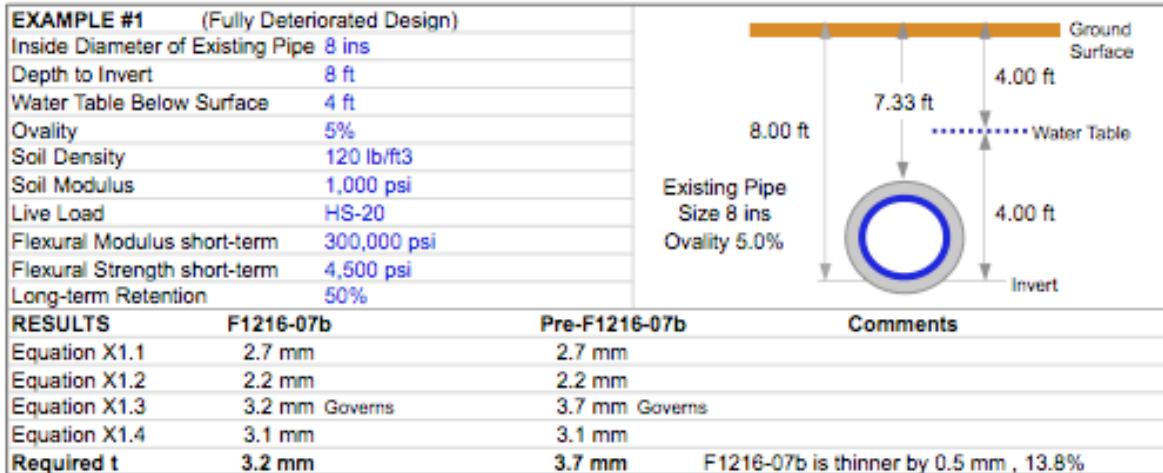| RESULTS	F1216-07b		Pre-F1216-07b		Comments
Equation X1.1	2.7 mm		2.7 mm		
Equation X1.2	2.2 mm		2.2 mm		
Equation X1.3	3.2 mm	Governs	3.7 mm	Governs	
Equation X1.4	3.1 mm		3.1 mm		
Required t	3.2 mm		3.7 mm		F1216-07b is thinner by 0.5 mm , 13.8%

Figure 3. Fully Deteriorated Design for 8" Liner. F1216-07b is 13.8% Thinner. Eq X1.3 Governs.

EXAMPLE #2 (Fully Deteriorated Design)

Inside Diameter of Existing Pipe	12 ins	
Depth to Invert	8 ft	
Water Table Below Surface	4 ft	
Ovality	3%	
Soil Density	120 lb/ft3	
Soil Modulus	1,000 psi	
Live Load	HS-20	
Flexural Modulus short-term	300,000 psi	
Flexural Strength short-term	4,500 psi	
Long-term Retention	50%	

Existing Pipe Size 12 ins, Ovality 3.0%

Ground Surface / 4.00 ft / 7.00 ft / 8.00 ft / Water Table / 4.00 ft / Invert

RESULTS	F1216-07b		Pre-F1216-07b		Comments
Equation X1.1	3.8 mm		3.8 mm		In F1216-07b, X1.4 governs
Equation X1.2	2.5 mm		2.5 mm		versus X1.3 pre-F1216-07b
Equation X1.3	4.4 mm		4.8 mm	Governs	
Equation X1.4	4.7 mm	Governs	4.7 mm		
Required t	4.7 mm		4.8 mm		F1216-07b is thinner by 0.1 mm , 2.3%

Figure 4. Fully Deteriorated Design for 12" Liner. F1216-07b is thinner by 2.3%. Eq X1.4 Governs.

EXAMPLE #3 (Fully Deteriorated Design)

Inside Diameter of Existing Pipe	24 ins	
Depth to Invert	12 ft	
Water Table Below Surface	6 ft	
Ovality	2%	
Soil Density	120 lb/ft3	
Soil Modulus	1,000 psi	
Live Load	HS-20	
Flexural Modulus short-term	300,000 psi	
Flexural Strength short-term	4,500 psi	
Long-term Retention	50%	

Existing Pipe Size 24 ins, Ovality 2.0%

Ground Surface / 6.00 ft / 10.00 ft / 12.00 ft / Water Table / 6.00 ft / Invert

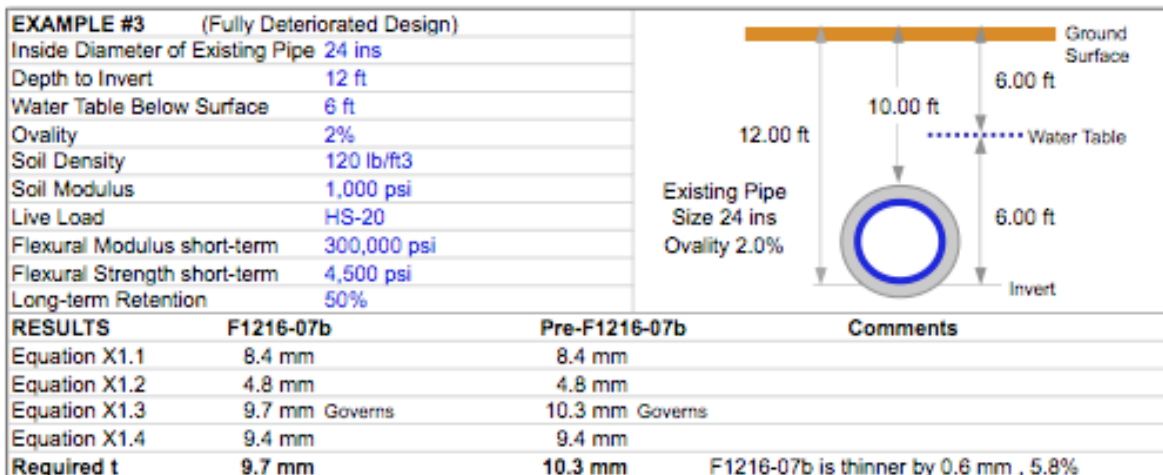| RESULTS	F1216-07b		Pre-F1216-07b		Comments
Equation X1.1	8.4 mm		8.4 mm		
Equation X1.2	4.8 mm		4.8 mm		
Equation X1.3	9.7 mm	Governs	10.3 mm	Governs	
Equation X1.4	9.4 mm		9.4 mm		
Required t	9.7 mm		10.3 mm		F1216-07b is thinner by 0.6 mm , 5.8%

Figure 5. Fully Deteriorated Design for 24" Liner. F1216-07b is thinner by 5.8%. Eq X1.3 Governs.

EXAMPLE #4	(Fully Deteriorated Design)		
Inside Diameter of Existing Pipe	36 ins		
Depth to Invert	12 ft		
Water Table Below Surface	6 ft		
Ovality	2%		
Soil Density	120 lb/ft3		
Soil Modulus	1,000 psi		
Live Load	HS-20		
Flexural Modulus short-term	300,000 psi		
Flexural Strength short-term	4,500 psi		
Long-term Retention	50%		
RESULTS	F1216-07b	Pre-F1216-07b	Comments
Equation X1.1	12.6 mm	12.6 mm	In F1216-07b, X1.4 governs
Equation X1.2	7.2 mm	7.2 mm	versus X1.3 pre-F1216-07b
Equation X1.3	13.8 mm	14.6 mm Governs	
Equation X1.4	14.2 mm Governs	14.2 mm	
Required t	14.2 mm	14.6 mm	F1216-07b is thinner by 0.5 mm , 3.1%

Ground Surface
6.00 ft
9.00 ft
12.00 ft ·········· Water Table
Existing Pipe Size 36 ins
Ovality 2.0%
6.00 ft
Invert

Figure 6. Fully Deteriorated Design for 36" Liner. F1216-07b is thinner by 3.1%. Eq X1.4 Governs.

EXAMPLE #5	(Fully Deteriorated Design)		
Inside Diameter of Existing Pipe	48 ins		
Depth to Invert	15 ft		
Water Table Below Surface	6 ft		
Ovality	2%		
Soil Density	120 lb/ft3		
Soil Modulus	1,000 psi		
Live Load	HS-20		
Flexural Modulus short-term	400,000 psi		
Flexural Strength short-term	4,500 psi		
Long-term Retention	50%		
RESULTS	F1216-07b	Pre-F1216-07b	Comments
Equation X1.1	17.4 mm	17.4 mm	In F1216-07b, X1.4 governs
Equation X1.2	11.5 mm	11.5 mm	versus X1.3 pre-F1216-07b
Equation X1.3	18.6 mm Governs	19.7 mm Governs	
Equation X1.4	17.2 mm	17.2 mm	
Required t	18.6 mm	19.7 mm	F1216-07b is thinner by 1.1 mm , 5.8%

Ground Surface
6.00 ft
11.00 ft
15.00 ft ·········· Water Table
Existing Pipe Size 48 ins
Ovality 2.0%
9.00 ft
Invert

Figure 7. Fully Deteriorated Design for 48" Liner. F1216-07b is thinner by 5.8%. Eq X1.3 Governs.

EXAMPLE #6	(Fully Deteriorated Design)		
Inside Diameter of Existing Pipe	60 ins		
Depth to Invert	20 ft		
Water Table Below Surface	10 ft		
Ovality	2%		
Soil Density	120 lb/ft3		
Soil Modulus	1,000 psi		
Live Load	HS-20		
Flexural Modulus short-term	400,000 psi		
Flexural Strength short-term	4,500 psi		
Long-term Retention	50%		
RESULTS	F1216-07b	Pre-F1216-07b	Comments
Equation X1.1	22.5 mm	22.5 mm	
Equation X1.2	15.1 mm	15.1 mm	
Equation X1.3	25.7 mm Governs	27.3 mm Governs	
Equation X1.4	21.5 mm	21.5 mm	
Required t	25.7 mm	27.3 mm	F1216-07b is thinner by 1.6 mm , 5.8%

Ground Surface
10.00 ft
15.00 ft
20.00 ft ·········· Water Table
Existing Pipe Size 60 ins
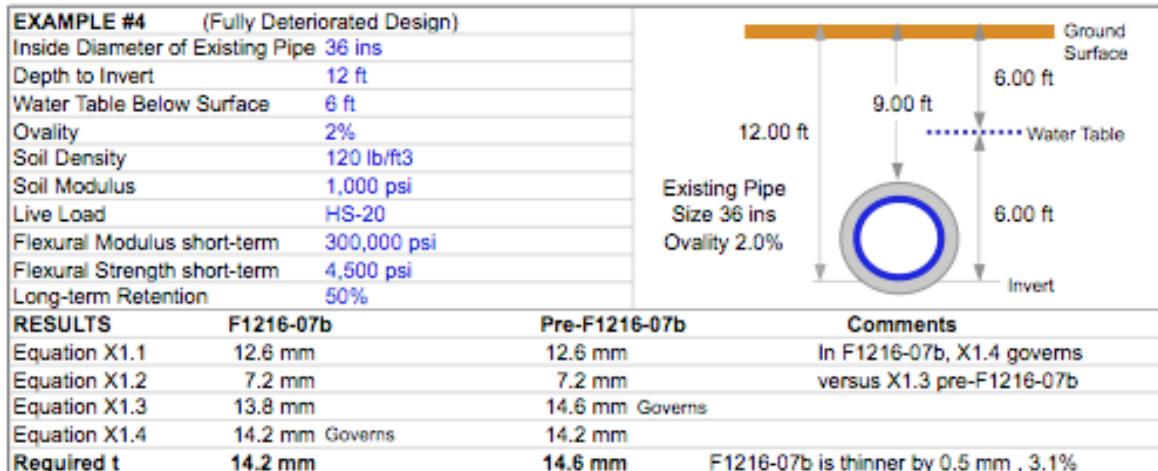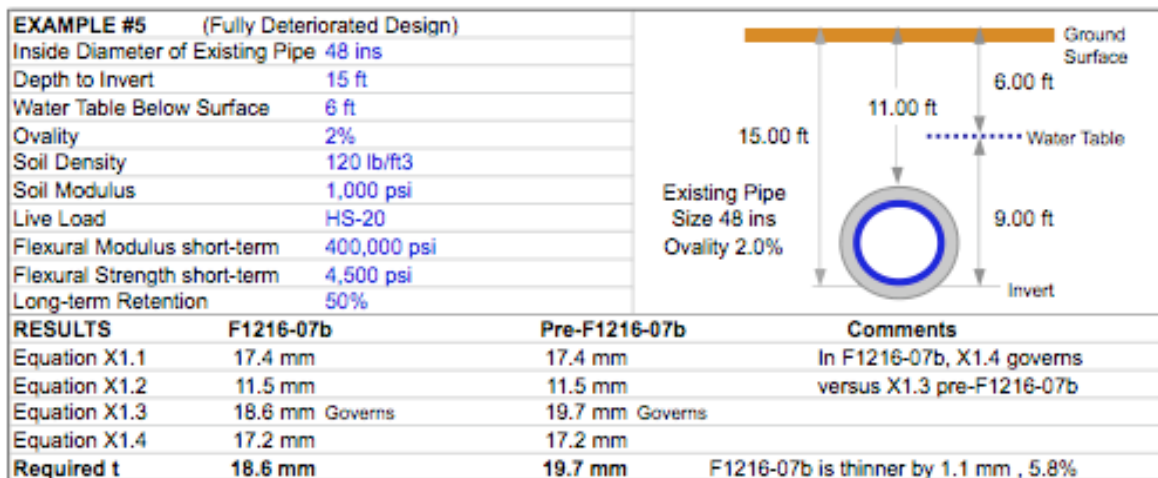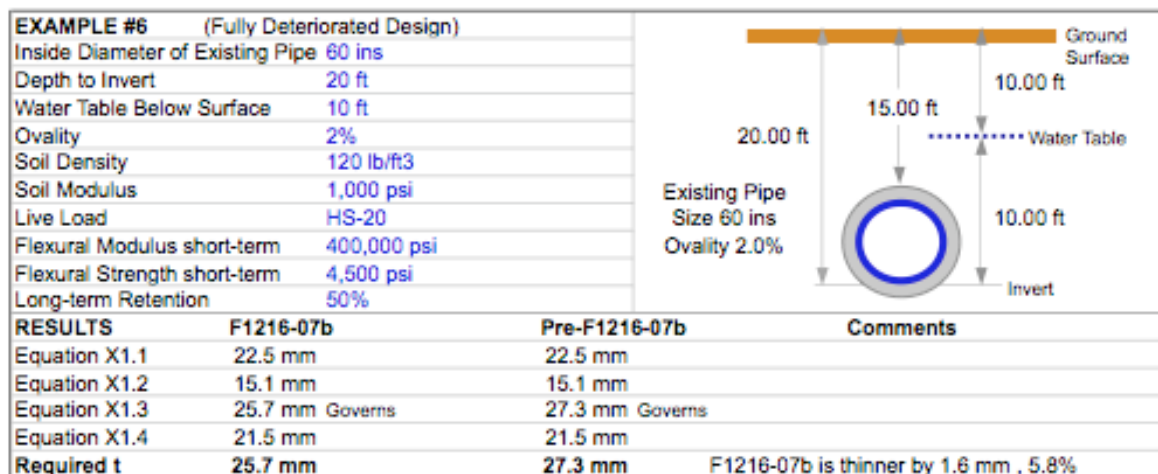Ovality 2.0%
10.00 ft
Invert

Figure 8. Fully Deteriorated Design for 60" Liner. F1216-07b is thinner by 5.8%. Eq X1.3 Governs.
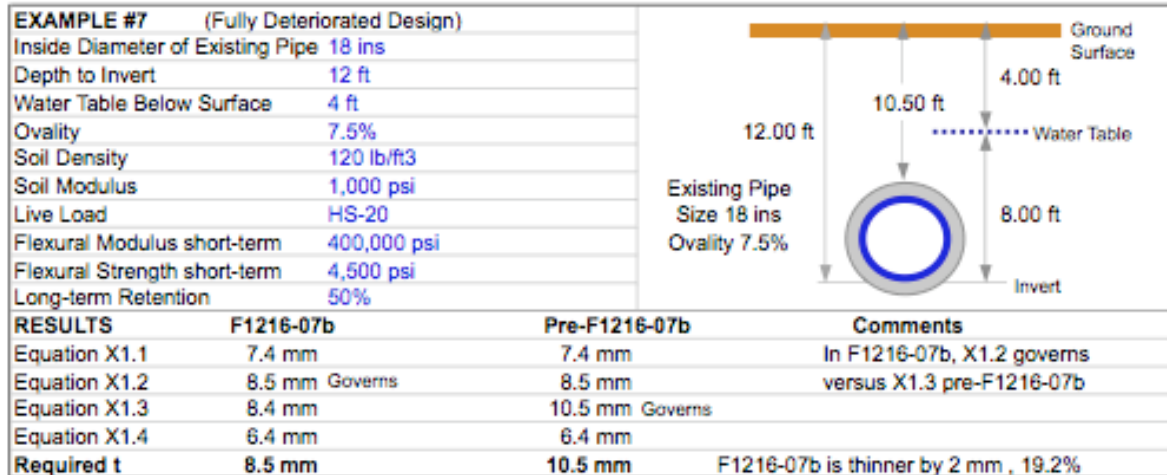
Figure 9. Fully Deteriorated Design for 18" Liner. F1216-07b is thinner by 19.2%. Eq X1.2 Governs.

RATIONAL FOR THE CHANGE

When the proposed change was put forward at the ASTM, two main rationales were provided in support of the change.

Rational #1: The original F1216-89 Appendix X1 equation X1.3 was said to be in error. After 17 years it was time to correct that error. The original X1.3 was said not to conform to a proprietary design document upon which the equations in Appendix X1 were originally based.

Rational #2: The effect of C in equation X1.3 was said to be not compatible with the effect of C in equation X1.1. Since each equation determines the liner's resistance to external load (in different situations), it was considered that the effect of C should be similar. Therefore equation X1.3 needed to be revised by moving C. The equations are shown below for comparison and the reader may judge this rational.

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

X1.1 can be re-arranged, without changing the calculation result, to:

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

Compare X1.1 above to the previous and new versions of X1.3 below.

$$ q_t = \frac{C}{N} [32R_W B'E'_S(E_L I/D^3)]^{1/2} \qquad\qquad [\text{X1.3 Pre F1216-07b}] $$

$$ q_t = \frac{1}{N} [32R_W B'E'_S \cdot C(E_L I/D^3)]^{1/2} \qquad\qquad [\text{Revised X1.3 in F1216-07b}] $$

It seems apparent that the effect of C in old equation X1.3 is identical to the effect of C in equation X1.1. Whereas, in the F1216-07b revised equation X1.3, the effect of C is no longer similar.

WHAT DOES THIS CHANGE MEAN TO CIPP LINER BIDS AND PROPOSALS?

Evaluating CIPP bids can be made difficult when competing bids are based on different liner thicknesses for the same installation. Such differences are valid when stemming from product differentiation, such as differing physical properties in liner modulus and strength among CIPP products. However when liner thickness differences among bids stem from different design installation parameters (such as ovality or water table), which by their nature, should be the same for all bids for the same installation, then bid evaluation becomes problematic. The advent of the ASTM F1216-07b adds a new problematic variable, design uniformity. Which design method was used? F1216-07b or pre F1216-07b? Which should have been used? Was it specified? Bid documents may need to state whether design is to be F1216-07b or pre 07b. There is current debate among some engineers and municipalities on this question with some opting to specify pre F1216-07b design method. Why is this?

The answer involves two areas. First is that some engineers and end users prefer the more robust approach to their sewer rehabilitations resulting from pre F1216-07b design. Second is that some find that the rational used for the F1216-07b change is not compelling. This reservation is not solely confined to some municipal and engineering communities. Some CIPP installation contractors also express reservation.

A LOOK AT HOW F1216-07b DESIGN MIGHT REDUCE CIPP COSTS

To the advantage of end users, CIPP sewer rehabilitation has become a highly competitive and widely used product. One, or a limited few, large suppliers/installers no longer control the marketplace. The proliferation of suppliers and installers has resulted in substantial cost reductions for end users. Sewer rehabilitation budgets now buy more miles of sewer rehabilitation than in the past. For installation contractors, costs broadly subdivided into installation costs and CIPP material costs. The material cost proportion generally increases as sewer size increases and in the larger sewer sizes, bid cost becomes increasingly a play on material costs. CIPP material costs are principally tube and resin. Tube and resin costs are fundamentally proportional to requirements for in-place liner thickness. Therefore, when the required in-place liner thickness is reduced, as may often occur from F1216-07b design, the cost of lining should fall. The following examples suggest how F1216-07b design could favorably impact CIPP lining costs.

Cost Example #1: 8" Sewer (Refer to Design Example #1, Figure 3)
Although nominal 4.5mm liner tubes are available, very often installers use nominal 6.0mm tubes for 8" sewers to make sure minimum thickness requirements are met. With the minimum thickness requirements, as determined by F1216-07b design, now reduced, the need to use a 6.0mm nominal tube is correspondingly reduced. Therefore, due to competitive situations, more bids for 8" sewers may be seen based on 4.5mm tubes than 6.0mm tubes. This results in savings on both tube and resin costs as shown in Table 3. As per F1216 requirements for resin (Section 7.2 Resin Impregnation), required resin quantity is based on nominal tube thickness.

Table 3. Cost Example for 8", 6.0mm versus 4.5mm Tube

Cost Example 1:	Sewer Size 8"	6.0mm versus 4.5mm tubes		
Nominal Tube	**Resin Qty**	**Resin Cost**	**Tube Cost**	**R + T Cost**
8" x 6.0	2.47lb/ft	$3.09/ft	$3.50/ft	$6.59/ft
8"x4.5	1.87lb/ft	$2.34/ft	$3.20/ft	$5.54/ft
Reduction	0.60lb/ft	$0.75/ft	$0.30/ft	$1.05/ft
	24.3%	24.3%	8.6%	15.9%

<u>Cost Example #2: 24" Sewer (Refer to Design Example #3, Figure 5):</u>
For the F1216-07b thickness of 9.7mm, a 10.5mm tube would likely be used. For the pre-F1216-07b thickness of 10.3 mm, a 12.0mm nominal tube would likely be used. As before, resin quantity required is based on the nominal tube thickness (refer F1216, section 7.2). Savings are shown in Table 4.

Table 4. Cost Example for 24", 12.0mm versus 10.5mm Tube

Cost Example 2:	Sewer Size 24" 12.0mm versus 10.5mm tubes			
Nominal Tube	Resin Qty	Resin Cost	Tube Cost	R + T Cost
24"x12.0	14.99lb/ft	$18.74/ft	$13.60/ft	$32.34/ft
24"x10.5	13.15lb/ft	$16.44/ft	$12.50/ft	$28.94/ft
Reduction	1.84lb/ft	$2.30/ft	$1.10/ft	$3.40/ft
	12.3%	12.3%	8.1%	10.5%

The above cost examples use a regular (unfilled) polyester resin and 5% excess resin.

A BIGGER PICTURE PERSPECTIVE

From a larger perspective, the reduction in CIPP liner thickness due to F1216-07b may have some big picture results for the end users (such as municipalities) and suppliers (such as installation contractors) that are not readily apparent. End users are increasingly employing asset management techniques to justify and allocate spending on sewer rehabilitation including CIPP lining. A key parameter in the asset management analysis is projected lifetime for the CIPP rehabilitation. A question to be considered (with difficulty) is whether less robust liners will have less robust life. In this context, less robust life includes not only overall lifetime but also O&M costs along the way. The watermain asset serves as an illustration of the importance of this consideration. The switch from cast iron to ductile iron watermain material was, in a large part, driven by product supply economics due to wall thickness reduction. In the main, it turned out that the old thicker cast iron had a significantly superior life cycle cost than the thinner ductile iron. Why was DI thinner than CI? The answer partly lies in a design change in the governing standard that allowed ductile iron to be thinner than cast iron resulting in a better capital cost situation for end users plus a more competitive situation for iron pipe suppliers. So the question becomes, will and should economically driven asset management models factor in an impact for less robust CIPP liners? If so, will the life cycle cost change be neutral, negative or positive for CIPP lining?

For suppliers and installation contractors, the question of risk has impact on pricing. Installation contractors may consider whether installing thinner liners may increase either warranty costs or the frequency of inevitable occasional installation problems. Less robust liners may result in less margin of safety from the contractor installation perspective. If suppliers and installation contractors consider their risk increased by supplying and installing thinner liners, this, in time, will be reflected in pricing.

CLOSING THOUGHTS

The change to the well-established and long-used F1216 CIPP liner design method brought about in F1216-07b, while not dramatic, does result in reducing fully deteriorated CIPP liner thickness in many typical situations. In general, the industry will see 5%-10% reduction in required fully deteriorated in-place liner thickness due to the F1216-07b Appendix X1 revision. In special situations the reduction can be 15-20% or higher. In essence, liners for fully deteriorated design become less robust than before F1216-07b. This change moves fully deteriorated liner thickness closer to partially deteriorated liner thickness.

This closing of the gap between partially and fully deteriorated liners, by reducing fully deteriorated thickness, may be discomforting and possibly surprising to many end users and engineers. Some may now consider that the margin of safety or comfort implied by the F1216 design concept of Fully Deteriorated is no longer sufficiently reflected in the F1216-07b design method. Others will counter that the concept of Fully Deteriorated is flawed, with cogent arguments put forward in support. Nevertheless,

although a key fully deteriorated design equation was revised in F1216-07b to give less robust results, the F1216 design concept of fully deteriorated was not changed. The design methodology in support of the fully deteriorated concept had functioned for 17 years prior to F1216-07b.

As and where the F1216-07b design method is accepted, the reduced liner thickness should be reflected in reduced prices for fully deteriorated liners. Along the way, issues may arise regarding whether F1216-07b or pre F1216-07b design is used or is to be used. Many players in the CIPP industry rely on old design tools and may be slow to upgrade resulting in inconsistencies.

Installation contractors may find it useful to determine whether bid documents are specifying F1216-07b or the previous F1216 design method. Designers and specification writers may find it useful to realize that, under F1216-07b, a specified ovality (E.G. 3%, 5% etc) will no longer produce liners as robust as was previously the case.

REFERENCES

ASTM F1216-07b, F1216-07a and F1216-89: Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube

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