CIPP PRESSURE PIPE DESIGN UPDATE – ASTM F1216 AND AWWA

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Since its initial release in 1989, ASTM F1216 has endured 14 revisions. Perhaps the most widely utilized and referenced industry standard for pipeline rehabilitation, it includes processes, performance requirements and guidelines which translate to other technologies beyond cured-in-place pipe (CIPP) installed by the inversion method, for which F1216 was originally developed. Design concepts included in non-mandatory Appendix X1 were originally established based on direct bury, flexible pipe theory, applied to homogeneous, CIPP liners that were unbonded to the host pipe, and adapted to account for host pipe containment. Design checks for CIPP installed within gravity-flow pipelines and low-pressure sewers with varying levels of host pipe deterioration were provided. Pressure pipe design checks were originally intended to account for buried sewers in surcharged conditions due to heavy rain events or force mains operating at low internal pressures, generally up to 10 psi. However, limitations on their use are not detailed in Appendix X1 which, combined with a lack of other industry standard pressure pipe design methods for close-fit lining systems, led to their widespread adoption across the pipeline rehabilitation industry, often without a full understanding of how to apply theory to practice.

Design checks for hole spanning in pressure pipes were developed by Joe Aggarwal in 1983 and incorporated in the first release of F1216 in 1989. This approach was based on plate bending theory published by R.J. Rourke and was used to analyze CIPP's ability to span a circular hole as a flat plate with a fixed edge. Subsequent review of Aggarwal's original derivations revealed a transcription error in Equation X1.5 with the utilization of constant 1.83 in lieu of the correct value of 1.63. Although this variance seems inconsequential at face value, sensitivity analysis revealed that differences in calculated results can be significant. In addition, previous versions of Equations X1.6 and X1.7 utilized dimension ratio (DR), or the ratio of outside diameter to wall thickness, which is not applicable to anisotropic composites such as reinforced CIPP, and inside diameter measurements of the CIPP instead of its mean diameter. The change to mean diameter results in a slight reduction in calculated internal pressure resistance with increasing diameter and wall thickness. Modifications to Equations X1.5, X1.6 and X1.7 were made and reflected in the 2024 and 2024a revisions of ASTM F1216 as summarized in the table below.

Pressure Pipe Design Check	ASTM F1216, Appendix X1 Equation	ASTM F1216 Editions	
		1989-2022 (13 total)	2024-2024a (2 total)
Hole Spanning	X1.5	$\frac{d}{D} \leq 1.83\left(\frac{t}{D}\right)^{1/2}$	$\frac{d}{D} \leq 1.63\left(\frac{t}{D}\right)^{1/2}$
	X1.6	$P = \frac{5.33}{(DR-1)^2}\left(\frac{D}{d}\right)^2 \frac{\sigma_L}{N}$	$P = 5.33\left(\frac{t}{d}\right)^2 \frac{\sigma_L}{N}$
Internal Pressure Resistance	X1.7	$P = \frac{2\sigma_{TL}}{(DR-2)N}$	$P = \frac{2\sigma_{TL}}{(D-t)N}$

In addition to pressure pipe design checks, ASTM F1216 requires that certain gravity pipe design equations be satisfied. For a partially deteriorated pressure pipe, resistance to hydrostatic buckling must also be checked per Equation X1.1. For fully deteriorated pressure pipe, Equations X1.1, X1.3 and X1.4 also must suffice. Equation X1.3 conservatively assumes that all surcharge loads (soil, groundwater, live and dead loads) are transferred to the CIPP, while X1.4 is a pipe stiffness check that applies to handling and installation of new pipe and is irrelevant to liner design. For gravity pipe design, Equation X1.4 can control, sometimes egregiously, and has been rightly removed from other relevant CIPP design appendices, including ASTM F2019 (UV cure GRP-CIPP) and F3541 (CIPP sectional repairs) but somehow still resides in F1216. Also, Equation X1.3 wrongly assumes groundwater to the top of pipe instead of the invert. This has also been addressed in F2019 and F3541 but has yet to be corrected in F1216.

It's important to note that pressure pipe systems which are structurally compromised or unstable as defined by ASTM F1216 for a fully deteriorated host pipe are not good candidates for CIPP lining and are generally repaired or replaced in kind using traditional methods such as dig and replace or pipe bursting. Pressure pipes identified for lining are predominantly structurally sound but may exhibit infiltration/exfiltration and some slight out-of-roundness due to wear, minor abrasion and/or surface corrosion. In this scenario, CIPP is designed to resist groundwater pressures or vacuum when out of service.

Although unlikely, once in service after CIPP lining, a host pipe that was once structurally sound may become unstable due to external corrosion or other reasons. If this scenario is expected, the CIPP would be designed to carry all anticipated external loadings, and mechanical properties utilized in design should reflect the duration and frequency of the applied loads.

From an industry standards standpoint, significant strides have been made in recent years to advance pressure pipelining design, with the publication of the AWWA Committee Report, "Structural Classifications of Pressure Pipe Linings" in 2019, followed by AWWA CIPP Standard C623 in 2022, and the evolving C623 design appendix which is currently being developed through the AWWA Pipeline Rehabilitation Committee. These advancements will help to normalize design practice and acceptance criteria for CIPP and other close-fit linings used in the structural renewal of pressure pipes.