Joint Integrity of Plastic Pressure Pipes in Municipal Service

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ABSTRACT

Plastic pressure pipes have been in use in North America for at least 40 years. Thermosetting plastics and thermoplastics commonly utilized in municipal pressure applications include fiberglass reinforced plastic pipes (FRP), polyvinyl chloride (PVC), high density polyethylene (HDPE), and more recently, fusible polyvinyl chloride (FPVC). Typically, these materials undergo hydrostatic pressure testing first in the manufacturing facility, then a second time in the field following installation. For field hydrostatic leakage testing, most pipe materials have an associated "allowable makeup water" or "allowable leakage" to accommodate the unique characteristics of the material as well as other irregularities during testing such as air in the line, temperature variations, and even instrument inaccuracies. Test methods and formulas for calculating makeup water usually vary based on the pipe material-specific standards. The wide discrepancies that exist for makeup water between different pipe materials do not place them on a level playing field for a given application. This paper is a review of both in-plant and in-field hydrostatic pressure testing and the topic of makeup water as outlined in AWWA standards for plastic materials. Quality control and qualification tests for joints of each pipe material standard are also reviewed. Recommendations are made for consideration by the Specification Engineering community for future revisions of standards pertaining to the field testing of plastic pipelines.

INTRODUCTION

Loss of water globally in municipal water distribution and transmission systems can be linked to faulty pipe joints and poor quality control practices both during manufacture and installation of pipes and appurtenances, poor manufacturing and performance standards, and in some cases, no standards at all. Approximately 20% of the water in municipalities in the United States serving more than one million people is unaccounted-for (van der Leeden et. al. 1990). In developing countries, these losses can be as high as 50%. According to the US EPA, 36% of the City of Boston's potable water is unaccounted-for. In 1977, this number was as high as 50% for Boston (Tullmin 2001-2007).

Plastic pipe materials commonly used in North American municipalities include fiberglass reinforced plastic pipes (FRP), polyvinyl chloride (PVC), high density polyethylene (HDPE), and more recently, fusible polyvinyl chloride (FPVC). Innovations and technological advances in the past 30 years have resulted in various high-performance plastic pipe jointing systems. Problems with gasket-joint PVC pipes such as fish-mouthing

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were resolved with the introduction of the metal-reinforced Reiber-type elastomeric seal (Rahman, 2007). The recent adoption of butt-fused HDPE and FPVC pipes in some municipalities now offers an opportunity to install thermoplastic pipes without gasket-sealed joints. Hydrostatic pressure testing of these pipe materials is typically performed twice, once at the pipe manufacturing plant to confirm structural integrity and proper manufacture, and again after the pipeline has been installed and backfilled to confirm that the pipe, joints, and thrust restraint systems have been properly constructed. New pipe joints usually undergo Qualification Testing to prove that their unique designs can provide a leak-free or "bottle tight" sealing mechanism.

Makeup Water – A Definition: The need for additional water to maintain the specified field hydrostatic test pressure in a newly-installed pipe system during in-field hydrostatic leakage testing is referred to as "makeup water" or "allowable leakage." This need is typically permitted to account for the unique characteristic of a pipe material as well as other initial irregular conditions in a new system. The expansion of HDPE pipe when pressurized is a unique property that must be addressed during pressure testing. Entrapped air, faulty connections between the pipe and other appurtenances such as valves, hydrants, fittings and service connections, proper seating of gaskets in pipe and appurtenances, shifting of fittings before joint restraint systems engage, temperature variations, or even instrumentation inaccuracies are all examples of anomalies within a test section that may require additional water to maintain test pressures. The term "allowable leakage" is misleading if interpreted as an allowance for actual pipe joints to leak. Leakage of pipe joints is not permitted as a general practice. Most standards now use the term "makeup water" or "test allowance" in lieu of "allowable leakage" for clarification.

While the topic of "allowable leakage" was discussed in a previous publication (Beieler, 2001), the intent of this paper is to revisit the topic almost a decade later, specifically for plastic pipes, in light of all the changes that have taken place in the revision of standards and design manuals.

PLASTIC PIPE MATERIALS

Beieler (2001) provides a discussion of methods and equipment for field hydrostatic testing as well as problems encountered during field testing. These topics are not discussed herein. An up-to-date review of each relevant plastic material standards and manuals, to gain an understanding of in-plant hydrostatic testing requirements, field hydrostatic testing, and joint performance requirements, follows.

FIBERGLASS REINFORCED PLASTIC (FRP) PIPE

Fiberglass reinforced plastic pipes (FRP) are a plastic material, but more specifically, thermosetting plastic. Once thermoset resins have cured, the material cannot be reshaped by heating/cooling. FRP pipes are mostly small diameter pressure pipes supplied to chemical process and oil field applications. In the municipal market, most FRP pipes are large diameter non-pressure pipes, though a small percentage is also used in pressure systems such as potable water distribution and transmission and sewer force mains. Pressure pipes must be manufactured to AWWA C950 (AWWA 2007a) or one of several ASTM standards. The AWWA Standard allows for pipes to be inside-diameter (ID) controlled (1-inch through 154-inch), or made to either IPS or DIPS diameter regimen. Pressure capacities increase in 50 psi increments, from 50 psi to 450 psi.

In-Plant Hydrostatic Testing: Unless an Owner does not require it, all pipes in the 1-in through 54-in diameter range undergo hydrostatic leakage testing by being pressurized to twice their pressure rating. For sizes greater than 54-in, the number of pieces of pipe to be tested is agreed upon by the manufacturer and purchaser. Test pressures are held for a minimum of 30 seconds and the pipe is not allowed to "fail, leak, or weep." Integral bells, including reinforcement sleeves or affixed couplings, are tested with the pipe.

Fittings are not addressed in C950, but receive some attention in the AWWA M45 (AWWA 2005a) design and installation manual. Fiberglass fittings are available in a variety of configurations and sizes and made by compression molding, filament winding, cutting and mitering, and contact molding. There is no pressure testing requirements given for fittings in M45.

Field Hydrostatic Testing: The AWWA Manual 45 for fiberglass pipe design recommends that pressure pipelines be tested after installation but does not provide any recommendations for test pressure or allowable leakage. One manufacturer of fiberglass pipe stated that a properly assembled field joint and a pipe that is not damaged by improper handling should have no leakage and recommends that the specification for field testing allow zero leakage. The lack of more detailed information on field hydrostatic testing in M45, again, may have to do with the small amount of FRP that is utilized in municipal pressure service.

Jointing: A variety of allowable joint types for FRP are mentioned in AWWA C950. Like other gasket-sealed plastic pipes such as PVC, AWWA C950 requires that gaskets used in FRP pipes meet the requirements of ASTM F477 (ASTM 2008).

Per AWWA C950, the joint performance for both bell-and-spigot or coupling joint with the gasket placed in the bell or on the spigot must meet the requirements of ASTM D4161 (ASTM 2001). This is a laboratory performance test of joint integrity, is not indicative of allowable angular deflections in the field, and is not a routine quality control measure for FRP. The importance of adhering to manufacturer's allowable joint deflections in the field is emphasized in the standard. Testing described in ASTM D4161 includes simulated pressurized in-use conditions with joints in maximum angular deflection, differential shear loading, and vacuum or external pressure conditions.

POLYVINYL CHLORIDE (PVC) PIPE

Polyvinyl chloride (PVC) pipe, like FRP, falls into the plastics group, but is a thermoplastic, not a thermosetting plastic. This means PVC, even after curing, can be reheated and modified and still retain its original physical/mechanical properties. The AWWA C900 (AWWA 2007b) standard covers polyvinyl chloride (PVC) pipe and fabricated fittings in sizes of 4-inch through 12-inch and pressure classes of 165 psi through 305 psi. Available dimension ratios include DR 14, 18, and 25 only. Pipe is made only to

CIOD regimen. The AWWA C905 (AWWA 1997) standard covers PVC pipe and fabricated fittings in sizes 14-inch to 48-inch and pressure ratings of 80 psi through 305 psi.

In-Plant Hydrostatic Testing: Pipes manufactured to both AWWA C900 and AWWA C905 are required to under-go an each-piece hydrostatic proof test, whereby every piece of pipe manufactured is pressurized to twice its designated pressure class for a minimum of five seconds and can not "fail, balloon, burst, or weep." Additionally, C900 pipes are required to undergo two other pressure tests. The first is referred to as the Sustained Pressure Test, and is intended to qualify the compound and extrusion process, and not serve as quality control for every piece of pipe manufactured. The second test, Pipe Burst Strength Test, ensures that pipes are capable of handling the short-duration high pressures that a piping system may be subjected to due to system surge conditions.

Fabricated fittings are manufactured from PVC pipes that meet all requirements of AWWA C900 and C905. A particular type and configuration of fitting fabricated to AWWA C900 must undergo the 1000-hour Sustained Pressure test. Every subsequent fiftieth fitting of the same configuration is then subjected to this test. All fittings fabricated to AWWA C905 must be tested at two times the pressure rating for a minimum of 2 hours.

Field Hydrostatic Testing: For a simultaneous pressure and leakage field test, AWWA C605 (AWWA 2005b) describes a 2-hour duration hydrostatic test where the PVC pipe is pressurized to 125% of the maximum anticipated sustained working pressure at the highest point along the test section. "Makeup water" for the test is defined by equation (1) below.

$$Q = \frac{LD\sqrt{P}}{148{,}000} \tag{1}$$

Where: Q = quantity of makeup water, gal/hr
L = length of pipe section being tested, ft
D = nominal diameter of pipe, in
P = average test pressure during hydrostatic testing, psi (gauge)

To pass the test, the water supplied to keep the system within 5 psi of the specified hydrostatic test pressure should not be greater than the amount calculated using Equation (1). The equation is based on a test allowance of 10.5 gallons per inch of diameter per mile per 24 hours (gal/in-dia/mile/day), at a pressure of 150 psi. Using Equation (1), the allowable makeup water will vary based on the test pressure. It should be noted that while the recommended test pressure is 125% of the maximum sustained working pressure at the highest point, Equation (1) defines P as the average pressure during testing. The term average pressure is not defined and should therefore be clarified in future revisions of the standard. The AWWA Manual 23 (AWWA 2002) provides another variation of Equation (1) that is based on the number of joints in a test section. Here again, the term P, test pressure, is not well defined, but M23 does provide a discussion on the selection of test pressures for an installed pipeline.

Jointing: Both AWWA C900 and C905 reference ASTM D3139 (ASTM 2005a) for the qualification and testing of assembled gasket-sealed joints. The tests are intended to evaluate the performance characteristics of the joint and are not routine quality control measures. Like FRP joint requirement, ASTM D3139 requires that gaskets meet the standard specification for elastomeric seals/gaskets for joining plastic pipe, ASTM D477. Additionally, it describes two tests for the qualification of gasket-sealed PVC pipe joints. The first is an internal pressure test on an axially deflected joint where the pipe sample is first pressurized up to 250% of its pressure rating for an hour, which is then followed by increasing the pressure to the pipe's minimum short-term rupture requirement, over a 60-70 second period without leakage. The second test involves application of a vacuum pressure to an axially deflected pipe joint sample.

FUSIBLE POLYVINYL CHLORIDE (FPVC) PIPE

First introduced in 2004, Fusible PVC pressure pipe is a relatively recent development in the municipal piping industry and is a proprietary product. Pipe meeting a proprietary formulation is extruded by various Vendor Manufacturers for the Technology Owner. Using fusion equipment and processes similar to those used for the heat fusion of HDPE pipe, but with different and unique heater surface temperatures, and heating, fusion and cooling pressures, lengths of FPVC pipes conforming to the requirements of AWWA C900 and C905 pipe are joined in the field for both trenchless and open-cut installations. Pipe availability and fusion capability are offered for all pressure classes and sizes listed in AWWA C900. However, for pipe meeting AWWA C905, all pressure classes and fusion capability are available only up to 24-inch. Beyond this, currently the largest available size is 36-inch, DR 32.5, pressure rated at 125 psi, with fusion capability.

Quality Control of Pipe: In addition to meeting and/or exceeding all in-plant quality control and pressure tests per AWWA C900 and C905, the Technology Owner requires extruders of the pipe to first pass their Vendor Qualification requirements that include manufacturing the pipe to a proprietary formulation that passes extensive testing of both the pipe and butt-fused joints. Vendors are also required to certify that the pipes they manufacture pass additional tests such as Heat Reversion and Loss on Ignition tests, neither of which is required by AWWA C900 or C905. Finally, third party testing and certification of every lot of pipe that is shipped is performed and includes a flattening test, heat reversion test, and acetone immersion test, all per appropriate AWWA and ASTM Standards.

Field Hydrostatic Testing: The Technology Owner's literature refers to AWWA C605 for hydrostatic leakage testing, but notes that this is only "for reference and those sections that contain gasketed fittings and connections or areas of other pipe technology." Literature further states that FPVC "joined with butt-fusion joints and installed per the manufacturer's instructions will not leak at the joints" (Underground Solutions, 2009). FPVC pipe systems have been field tested at pressures ranging from a system's operating pressure to 150% of the rated pressure of the pipe and durations have ranged from 2-hours to 24-hours. However, "the normal average parameters have been 150% of the operating pressure of the system for durations of 1 to 2 hours" (Underground Solutions 2009).

Joints: In-field quality control of butt-fusion joints includes the recording of all critical data such as ambient conditions, temperatures, pressures, etc. using data logging devices. This is done with every single joint. The data is linked to the specific certified fusion technician installing the joints, as well as all material and quality data for the pipe lot, and compared to qualified parameters as a quality control measure for the fusion.

Third party testing to ensure that the butt-fused joints are capable of meeting and/or exceeding the joint restraint requirements of PVC pipes per ASTM F1674 (ASTM 2005b) have also been performed. 6-inch Fusible PVC has been successfully cycled 3.5 million times (ASTM F1674 requires 1 million cycles) at pressures of 99 psi to 198 psi without failure. This equates to the ability of the FPVC pipe to undergo eight pressure surge cycles per hour for 50 years. The pipe has also exceeded the Sustained Pressure Test requirements outlined in ASTM F1674 by being tested for 5000 hours instead of the required 1000 hours.

HIGH DENSITY POLYETHYLENE (HDPE) PIPE

High Density Polyethylene (HDPE) pipes are thermoplastics and fall into the same general materials group as PVC, though the two materials have significantly different strength properties. The AWWA C906-07 (AWWA, 2007c) standard covers HDPE pressure pipe in sizes 4-inch through 63-inch, ranging in pressure classes from 51 psi (DR 32.5) through 254 psi (DR 7.3), for PE3408, with a Hydrostatic Design Basis (HDB) of 1600 psi. In recent years, PE4710, which also has an HDB of 1600 psi, has also been used in pressure applications. The dimension ratio (DR) most commonly specified in water systems is DR11, pressure class 160 psi. Pipe is manufactured to both IPS and DIOD (or DIPS) diameter regimen.

In-Plant Hydrostatic Testing: The standard requires a shop hydrostatic test, referred to as the "five-second pressure test," whereby only once per production run, a pipe or fitting is pressurized to four times its pressure class for five seconds and is not permitted to "burst, crack, split, or otherwise fail." This test may be substituted with the ring-tensile strength test, or the quick-burst test. For fabricated fittings, the five-second pressure test is required to be run on the first fitting of a particular outside diameter and style and every fiftieth fitting thereafter. Injection molded fittings are tested only once per production run. The five-second pressure test can not be substituted with other tests for fittings.

Field Hydrostatic Testing: When under pressure, HDPE pipes exhibit significant expansion due to a low modulus (or stiffness), and Poisson effects, making it relatively more difficult to conduct field hydrostatic pressure leak testing of the pipe compared to other more rigid thermoplastic pipe materials such as PVC. The AWWA M55 (AWWA, 2006) Manual of Design and Installation of HDPE pipe is currently in its first edition. For leakage testing, M55 refers to ASTM F2164 (ASTM, 2007). Originally published in 2002, this ASTM standard was revised in 2007.

The test method described in ASTM F2164 is a significant departure from what had traditionally been used for the leakage testing of HDPE pipe and still used for other water pipe materials. In the traditional test method for HDPE, described in the AWWA

Committee Report (AWWA 1998), the precursor to the AWWA M55 design and installation manual, a tabulated listing of allowable makeup water by nominal pipe sizes for a 1, 2, or 3 hour leakage test in units of gal/100 ft of pipe was provided. In this method, immediately following the initial 4-hour expansion phase, the amount of makeup water required to maintain test pressure for 1, 2 or 3 hours was monitored. If the amount of makeup water needed to maintain test pressure did not exceed the amounts presented in the table of allowable makeup water, then the pipe passed the test. This method was in line with the general test method for all municipal pipe materials. The method was also recommended and specified by HDPE Manufacturers (Chevron Phillips Chemical Company, 2006) as well as the Plastic Pipe Institute (PPI).

In ASTM F2164, the term "makeup water" has been separated from "allowable leakage" by inclusion of a statement that "there is no leakage allowance for a section of heat-fusion joined polyethylene piping, because properly made heat fusion joints do not leak." Though makeup water is mentioned, *it is not quantified*, a significant departure from generally accepted methods.

Since the allowable makeup water is no longer quantified, specifiers can get an idea of the makeup water needed for the 1-hour test phase of HDPE pipe by referring to the old tables (Chevron Phillips Chemical Company 2006). For a 2-hour field leakage test, makeup water allowance is 8.9 gal/100 ft for 24-inch pipe, 18 gal/100 ft for 36-inch pipe, and 31.4 gal/100 ft for 54-inch pipe. There does not appear to be a linear relationship between test pressure and makeup water, i.e. expansion of the pipe is not linear to applied pressure.

The current method described in ASTM F2164-07 consists of two phases, an Initial Expansion Phase, and a Test Phase. In the initial expansion phase, the pipe is pressurized to a maximum of 1.5 times the system design pressure, at the lowest elevation in the test section, for up to 4 hours, adding as much volume of water as necessary to maintain the test pressure for the 4-hour duration. During this portion of the test there is no pass/fail criteria applied, and the total amount of water introduced or total volumetric change in the pipe is not considered. At the end of the 4 hours, the pressure is reduced by 10 psi, to arrive at the "test phase pressure." The test phase is conducted for 1 hour only. HDPE is one of the few pipe materials that do not recommend a minimum two-hour duration test. If there are no visible leaks and the pressure remains within 5% of the test phase pressure, without additional water being introduced, then the pipe system passes the test. The potential water volume lost or volume gained by expansion is not directly addressed.

Jointing: AWWA C906 provides minimal information on the joining of HDPE pipe systems, and makes reference to AWWA M55 for more detailed discussions on joints. HDPE pipes are most commonly joined by heat fusion. For fittings and other appurtenances, when appropriate, mechanical connections are also specified that provide both a seal and restraint against joint separation. Butt fusion is the most common method of joining HDPE pipe and fittings. Socket fusion is sometimes used in small diameter systems, while electrofusion is used when incorporating saddles and service connections. Flange assemblies and mechanical joining methods are used, when appropriate, for pipe-to-fitting connections.

Assembly of HDPE pipes using butt fusion requires trained operators and fusion machines. The fusion process involves adherence to specific parameters such as heater surface temperatures, and heating, fusion and cooling pressures for a successful joint. M55 reiterates the importance of always observing manufacturer's recommended fusion procedures. It also talks about the availability of data logging devices that record the critical joining parameters which can later be compared to qualified parameters as a quality control measure for the fusion. While HDPE industry literature does not mandate the use of data loggers, it is the opinion of the authors that data loggers be utilized on all projects where HDPE is joined by butt fusion, even if it is an added cost to the project. It provides a long-term means of keeping QA/QC records on the fusion of each joint and is the only sure way of monitoring the quality of butt-fused joints.

DISCUSSION OF HYDROSTATIC TESTS

In-plant hydrostatic testing of all pipe materials has been summarized in Table 1. The following points should be noted:

a) Between the various plastic pipe standards, there is a difference in both the required test pressure and the duration of the test.
b) Some standards require in-plant testing of each piece of pipe while others require testing only a representative sample.
c) Of the standards discussed in this paper, only one states that in-plant testing is optional.

Table 2 summarizes field hydrostatic testing of pipe materials. The following points should be noted:

a) Some material standards provide an equation for the calculation of allowable makeup water that incorporates the test pressure --- higher test pressures allow for higher makeup water. Others do not quantify makeup water at all. Still, others provide no guidance at all on hydrostatic pressure testing.
b) Plastic pipe material installation standards recommend a test pressure of 125 % or 150% of operating pressure or working pressure of a pipeline.
c) Some standards base the test pressure on a percent of the pressure at the lowest point, while others use the high point as the basis.

CONCLUSION & RECOMMENADATIONS

- The term "allowable leakage" should not be interpreted as an allowance for gasket-joint pipes to leak when installed. All pipe material installation standards should use terms such as "allowable makeup water" or "test allowance" in lieu of "allowable leakage" to prevent confusion. It is also paramount that installation standards do not display tables which quantify "leakage" per number of joints (AWWA, 2002) --- this is misinterpreted as an allowance for the pipe joints to leak.
- The Engineer's selection of test pressures over the maximum working pressure should be carefully considered because an excessively high allowance can increase the cost of a system by increasing the pressure rating of all other system components.

- It is the opinion of the Authors that for formulas with pressure as a variable, an "average test pressure" should be utilized by taking pressure readings at several locations between the highest and lowest points of a pipeline. A vertical rise of 100-ft results in an increase of 43 psi of head pressure added to the line pressure as measured at the lowest point.
- If more than one pipe material is allowed on a project, owners, specifiers, and designers should develop testing requirements that are fair and uniform based on the pipe materials and joints that have been selected or at least recognize the different leakage allowances between pipe joints and materials when selecting or evaluating joints or materials that should be used.
- The allowable makeup water during field testing should be calculated as part of the design process, and evaluated by the owner and design team. Since the quantity of allowable makeup water for long, large diameter can be quite significant, the owner and design team should agree that if all the makeup water was leaking from one, poorly assembled joint, that the quantity of makeup water is acceptable. If it is not acceptable, the length of the pipe segment being tested should be reduced.
- Identifying a defective joint during the installation phase of a project, rather than the hydrostatic test phase, can avoid significant effort to locate a problem after the trench is backfilled. If a relatively simple field test of assembled joints can be performed, this test should be required in the specifications.

Table 1: Plastic Pipe Material In-Plant Hydrostatic Test Comparisons

Pipe Material Type / Standard	Test Required	Every Piece	Pressure / Duration	Other Details
Fiberglass / AWWA C950	NO, , subject to agreement with purchaser	NO, subject to agreement with purchaser	If required, then 1-in to 54-in tested @ 2 times pressure rating of pipe, for 30 seconds	Larger sizes are also tested per agreement with Purchaser. "Not allowed to fail, leak, or weep." Integral bells, including reinforcement sleeves or affixed couplings are tested w/ pipe
PVC / AWWA C900 and C905	YES	YES	2 times pressure class of pipe, for 5 seconds	Other tests include 1000-hr. Sustained Pressure Test, semi-annually, and Pipe Burst Strength Test, once every 24 hours
Fusible PVC (Proprietary Product) / AWWA C900 / C905	YES	NO	2 times pressure class of pipe, for 5 seconds	Proprietary product. Testing is loosely based on AWWA C605, Engineer typically specifies joint performance requirements. Per Technology Owner literature, "FPVC joined with butt-fusion joints and installed per the manufacturer's instructions will not leak at the joints." Other Quality Control measures in place.
HDPE / AWWA C906	YES	NO	4 times pressure class of pipe, for 5 seconds	Test is run only once per production run. Test can be substituted with Ring-Tensile Strength Test or Quick-Burst Test

Table 2: Plastic Pipe Material Field Hydrostatic Leakage Test Comparisons

Pipe Material Type / Standard	Test Pressure	Duration	Location of Test Pressure Reading	Makeup Water / Allowable Leakage	Comments
Fiberglass / AWWA C950, per AWWA M45	No recommendations	N/A	N/A	N/A	NO FORMULA. Zero Leakage per one Manufacturer
PVC / AWWA C900 and C905, per AWWA C605 and AWWA M23	125% of maximum anticipated sustained working pressure	2 hours	At highest point along test section	Formula based on 10.5 gal/in-dia/mile/day @ 150psi. Will vary by Test Pressure	FORMULA PROVIDED. Term used in Standard: "ALLOWABLE LEAKAGE," "TEST ALLOWANCE," and "MAKEUP WATER"
Fusible PVC (Proprietary Product) / AWWA C900 / C905, per Technology Owner Literature	Per AWWA C605, or system operating pressure, or 150% of pressure rating of pipe	Average 1 to 2 hours	Lowest point in each test section	"FPVC joined with butt-fusion joints and installed per the manufacturer's instructions will not leak at the joints"	AWWA C605 referenced in literature for gasket-joint components of a system. Otherwise no leakage at butt-fused joints.
HDPE / AWWA C906, per AWWA M55, and ASTM F2164	1.5 times the design working pressure	1 hour	Lowest point in each test section	No quantification of allowable makeup water.	As much water as necessary can be pumped in to hold pressure for 4-hr during expansion phase. Make-up water is not quantified and allowable pressure drop is up to 5% of the test pressure

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