

**Design Service Life
Of
Corrugated HDPE Pipe**

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Foreword

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The purpose of this technical report is to provide important information available to PPI on the design life of corrugated HDPE pipe.

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The Plastics Pipe Institute
Toll Free: (888) 314-6774
<http://www.plasticpipe.org>

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Introduction:

Thermoplastic pipes began to be used over 50 years ago in Europe and North America for water and sewer applications. Polyethylene pipe has been used for drainage applications in the United States for over 35 years and for highway pavement underdrain applications for 30 years. These pipe were generally 150mm (6 inch) in diameter and smaller. As use and applications for these materials expanded and as diameters increased questions concerning design service life and materials properties became significant issues. Designing with thermoplastic materials requires an understanding of viscoelastic or viscoplastic materials. The mechanical strength of these materials has to be put in relation to the forces acting on it, the stress, the loading time, and the temperature. The properties of primary concern are tensile yield strength and flexural modulus (because those are used in the design code); which are directly related to and proportional to density and, to a lesser extent, molecular weight. The values that truly govern how well, and for how long, the pipe performs are compression strength and flexural modulus; because the compression strength determines the pipe hoop compression stiffness and the flexural modulus determines the pipe or ring stiffness.

Any discussion of buried pipe service life can not ignore installation quality and practice. All buried structures, regardless of material, are structures of the soil and the pipe or structure, interacting with each other to carry the required loads. Poor installation practice will lead to poor performance of the soil-structure interaction system. AASHTO provides conservative installation guidance in Section 30 of the "AASHTO Standard Specifications for Highway Bridges." Similar installation requirements are provided in ASTM D 2321, "Standard Practice for Underground Installation of Thermoplastic Pipe for Sewers and Other Gravity-Flow Applications." Proper installation practice can contribute greatly to long-term system performance.

Current Specifications:

The current AASHTO (American Association of State Highway and Transportation Officials) specifications covering corrugated polyethylene pipe include Standard Specification for Corrugated Polyethylene Pipe, 300- to 1200-mm Diameter, AASHTO Designation: M 294-02 and AASHTO LRFD Bridge Design Specifications, Section 12 – Buried Structures and Tunnel Liners. AASHTO M 294 requires that the pipe be manufactured from materials (resins) as defined in paragraph 6.1.1:

“Extruded Pipe and Blow Molded Fittings – Pipe and fittings shall be made of virgin PE that conform with the requirements of cell class 335400C as defined and described in ASTM D 3350, except that the carbon black content shall not exceed five percent, and the density shall be not less than 0.945 gm/cc nor greater than 0.955 gm/cc. Resins that have higher cell classifications in one or more properties, with the exception of density, are acceptable provided product requirements are met. For slow crack growth resistance, acceptance of resins shall be determined by using the single point notched constant tensile load (SP-NCTL) test according to the procedure described in Section 9.5. The average failure time of the five specimens must exceed 24 hours with no single test specimen’s failure time less than 17 hours.” From this resin description, Section 12 of the AASHTO LRFD Bridge Design Specifications sets material properties for design in Table 12.12.3.3-1 as follows:

| Type of Pipe | Minimum Cell Class ASTM D 3350 | Allowable Long-Term Strain % | Initial F_u min (MPa) | Initial E min (MPa) | 50-Year F_u min (MPa) | 50-Year E min (MPa) |
|-----------------------------------|-----------------------------------|------------------------------|-------------------------|---------------------|-------------------------|---------------------|
| Corrugated PE Pipe – AASHTO M 294 | 335400C | 5 | 20.7 | 758 | 6.21 | 152 |

These values represent the minimums for the cell classification from ASTM D 3350 and do not represent what the industry is actually using. They also represent initial material properties values based on a specific loading regime that may or may not be representative of actual loading conditions. The initial flexural modulus value is based on tests conducted in accordance with ASTM D 790, Method 1, Procedure B, loading a 50mm specimen, 3.2mm thick and 12.7mm wide at a crosshead speed of 12.7mm/minute with the average value of the secant modulus calculated at 2% strain in the outer fibers. The initial tensile strength at yield is determined in accordance with ASTM D 638 using a “dogbone” specimen 1.9mm thick loaded at a rate of 50 mm/minute. The 50-year values for tensile strength and flexural modulus were selected based on resins used in the 1980s with some additional safety factors, and do not apply to resins currently required and used by the industry. The use of a “50-year” value is an arbitrary carry-over from the gas pressure pipe industry, where results from HDB testing, conducted for 10,000 hours (1.14 years), are projected forward to 50 years, with a safety factor. If 10,000 hours is projected forward two orders of magnitude, to 1,000,000 hours, that would equate to 114 years.

Current Materials (initial properties):

Resins currently utilized by the corrugated PE pipe industry exceed a minimum density of 0.948 gm/cc and have a melt index of less than 0.4 gm/10 minutes. These resins have a minimum initial tensile yield strength of 22.75 MPa (3,300 psi) and a minimum initial flexural modulus of 900 MPa (130,500 psi), as tested in accordance with ASTM D 3350. As density increases, these values both increase, linearly. (See Figures 1 and 2) (1)

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Figure 1. Tensile vs. Density

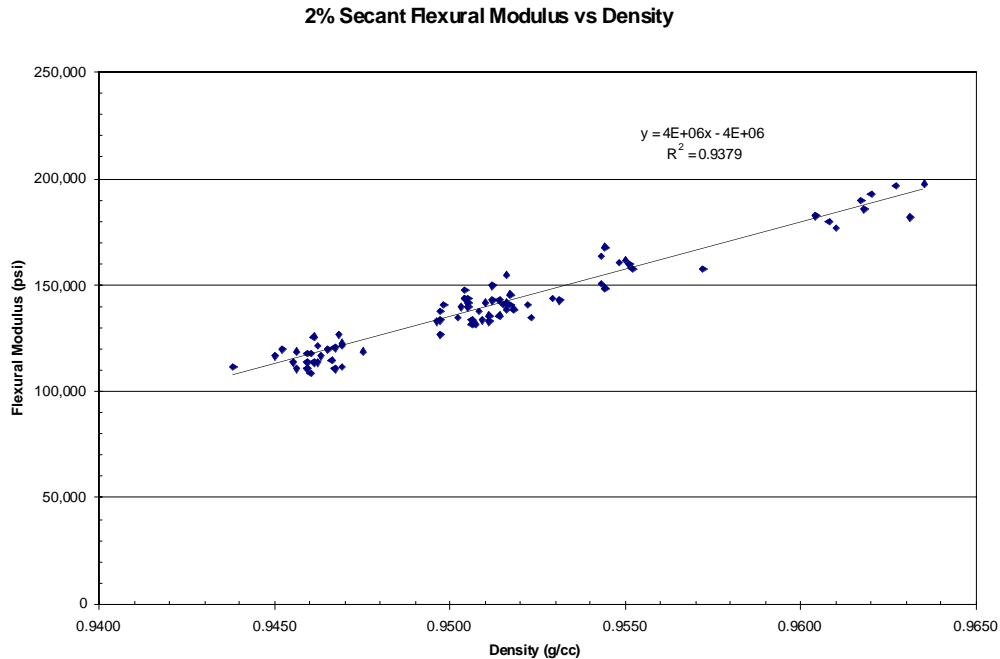


Figure 2. Flexural Modulus vs. Density

Long-Term Properties:

1. Tensile Strength:

Tests (a stress regression test) of a specific resin used by the corrugated PE pipe industry in the early 1980s, a 0.952 gm/cc density material with a 0.4 gm/10 min melt index, demonstrated a 100,000 hour hoop tension strength of 9.24 MPa (1,340 psi) and a 50-year value of 8.5 MPa (1,233 psi). If the test curve is projected to 1,000,000 hours, the design tensile strength value would be 7.5 MPa (1,080 psi). (2)

2. Modulus of Elasticity:

Dr. Lars-Eric Janson has published several articles plus a textbook in which he presents his work in developing a long term modulus of elasticity, or a relaxation modulus. In his tests, one pipe is deflected to 5% vertical deflection between parallel plates and held, in some cases for 9 years, and the stiffness regression recorded, which directly relates to the relaxation of the modulus of elasticity. In another series of tests, pipe was deflected to 4.3% and 13.6% and held for 8 years, with the same regression being recorded on a log scale. The regression curves can be project to 100 years, which is slightly over one order of magnitude from the period tested. Further, Dr. Janson found that tests conducted for as little as 100 hours were sufficient to make safe extrapolations up to 50 years or more for PE pipe. (3, 4)

Similar tests were conducted by Dr. Lester Gabriel at California State University on 24 pipe samples utilizing both the parallel plate test with samples deflected 5% and held, and the curved beam test, developed by Dr. Gabriel and Jim Goddard, with pipe wall samples subjected to 5% chord shortening. Pipe samples included 7 different diameters and represented 4 different manufacturers. From those tests, the relaxation curves were developed and extrapolated to 100 years. The curves were consistent in shape and slope, and the reduction in modulus from 50 to 100 years was a consistent 3% for both test methods. (5, 6)

Based on this testing, it should be appropriate to change the properties table in AASHTO Section 12 as follows:

| Type of Pipe | Minimum Cell Class ASTM D 3350 | Allowable Long-Term Strain % | Initial F _u min (MPa) | Initial E min (MPa) | 50-Year F _u min (MPa) | 50-Year E min (MPa) | 100-Year F _u min (MPa) | 100-Year E min (MPa) |
|-----------------------------------|-----------------------------------|------------------------------|----------------------------------|---------------------|----------------------------------|---------------------|-----------------------------------|----------------------|
| Corrugated PE Pipe – AASHTO M 294 | 335400C | 5 | 22.75 | 900 | 8.5 | 179 | 7.5 | 174 |

A corresponding change should be made to the AASHTO M 294 specification, increasing the minimum resin density to 0.948 gms/cc from the current 0.945 gms/cc.

These “long-term” values, at 50 and 100 years, are meaningful in design only if the stress is kept constant and there is no restraint on deformation. As stated by Dr. Janson in discussing the soil-structure interaction, “during the first years, the soil undergoes the reconditioning and settling that the backfilling technique has not succeeded in achieving, but which nature, with the help of traffic loading, groundwater movement, soil creep, soil frost action, etc. finally takes care of.” “During this time the pipe impulsively fights against additional deflection by virtue of its short-term ring stiffness.” “When the surrounding filling has found its shape and this shape fits the pipe’s deflected shape, no further change in the pipe shape of any practical importance takes place.” Therefore, it is really the initial values that should have more impact on design of gravity flow pipe. (3) Two other papers of interest in this area include another by Dr. Janson titled “Short-Term Versus Long-Term Pipe Ring Stiffness in the Design of Buried Plastic Pipes,” (7) and one by Elzink and Molin titled “The Actual Performance of Buried Plastic Pipes in Europe Over 25 Years.” (8) In the paper by Elzink and Molin, they state that deflection becomes stable in a relatively short period of time and then remains constant. Janson states; “deflection will reach a constant value within a

period of 2 – 3 years.” He also states that, “in traffic areas this period is found to be shorter. Thus, stresses beyond this point tend to regress, while soil remains stable around the pipe. This would not apply to pipe installed in soils or conditions that do not consolidate or stabilize, but those soils should not be placed around buried pipes of any type and are not permitted in the AASHTO construction standards.

Further, using the AASHTO design procedure, as contained in Section 12 of the “AASHTO LRFD Bridge Design Specification,” as well as reviewing the research on buried thermoplastic pipe, the pipe is found to be under hoop compression, with tension being limited and at a fraction of allowable levels. Thus, the point in time at which any tensile failure might occur is very far distant. In compression, Slow Crack Growth does not occur.

Even with those “initial” values, the “instantaneous” modulus and tensile yield are considerably under-estimated. For live loads, such as a truck crossing over a buried pipe at 95 KPH (60 MPH), the effect on the buried pipe takes less than a second. Another way to look at these time effects is to return to the relaxation modulus curves developed by Dr. Gabriel and Jim Goddard. For a standard pipe stiffness test per ASTM D 2412, run at 12.7mm per minute (0.5 inches per minute), the test on 1500mm (60”) pipe takes 6 minutes. In relation to the “instantaneous” modulus from the tests and the 100-year value, in 6 minutes approximately 40% of the relaxation has occurred. That is consistent for all of the HDPE curves. (5)

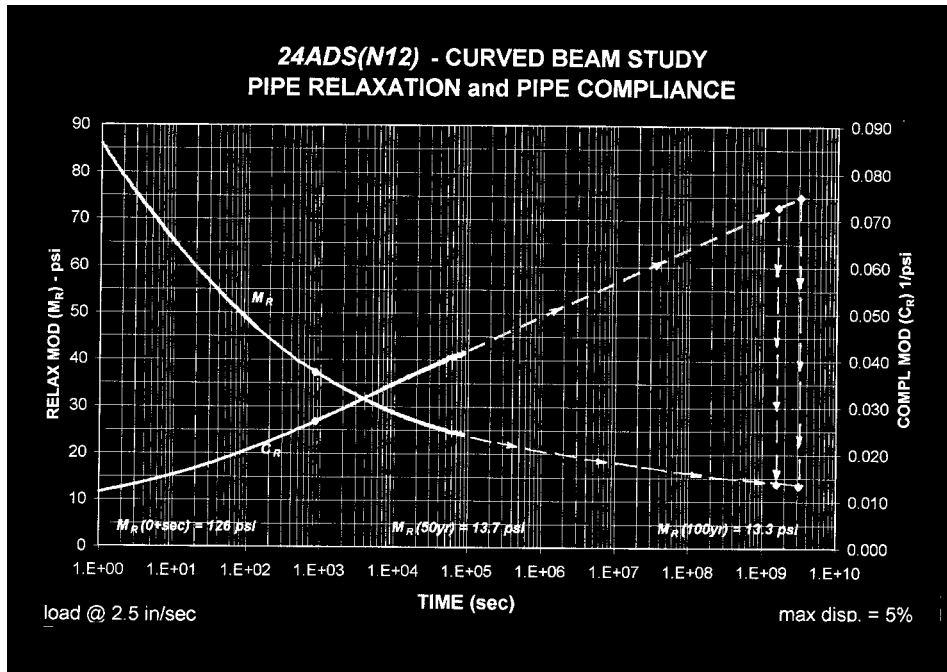


Figure 3 – Relaxation Modulus Curve – from Dr. Lester Gabriel

Another report that is helpful when considering the implications of a deeply buried pipe over a long period of time is the "Pennsylvania Deep Burial Study 15 Year Summary Report" prepared by James B. Goddard and submitted to the Pennsylvania Department of Transportation in August of 2002. This report covers the inspection of a 600mm (24 inch) diameter corrugated polyethylene pipe installed in 1987 under Interstate 279 north of Pittsburgh, Pennsylvania. This pipe has 30.5 meters of fill (100 feet) over it. Based on inspections completed in the summer of 2002, there has been no significant change to this pipe in the last 7 years. The only documented problem with this installation is some cracking in the Type C pipe under the couplings under 21 meters (70 feet) or more of fill, which have not spread to or appeared in the pipe wall outside the couplings. If the relaxation curves developed from the work by Les Gabriel and Jim Goddard are used to predict a potential spread of that cracking to couplings under lesser fill heights, and 70 feet of soil pressure for 15 years is used as the base, then cracking should appear under couplings with 64 feet of fill at 100 years. This makes some interesting and conservative assumptions, primarily that the pressure on the pipe remains constant for that period of time, where it is more likely that the pressure will decrease substantially, and probably has already since no change in the cracking could be identified over the last 7 years. Pipe shape and/or deflection has not changed in the last 10 years. A full summary report of this work has been delivered to PennDOT for their review and comments along with a complete set of referenced reports totally over 1,000 pages of data. (9)

Another report that adds support to the very long design service life of corrugated polyethylene pipe is "Clogging of Perforations in Plastic Drain Pipe" by by Glen Sanders and John Ellis of the U. S. Department of the Interior, Bureau of Reclamation. As the title indicates, the principle point of this study was to determine the extent of clogging of pipe perforations by backfill envelope materials. The report states that, after 29 years of service, "None of the pipe samples were extensively clogged by the envelope material." The report goes on to state that "All but one of the perforated pipe samples passed strength and impact tests currently required of new pipe used in Reclamation construction of subsurface drains." Also; "It should be noted that some of the pipe samples were produced before the earliest flexible plastic pipe standards were developed in the mid-70s by American Association of State Highway and Transportation Officials (AASHTO), American Society for Testing and Materials (ASTM), and USBR." None of this pipe was buckled or cracked. (10)

Chemical resistance and abrasion resistance are also design service life issues. Both are covered well in a Corrugated Polyethylene Pipe Association document entitled "Chemical & Abrasion Resistance of Corrugated Polyethylene Pipe." This includes a summary of abrasion testing conducted at California State University – Sacramento by Dr. Lester Gabriel as well as field performance data from a 1981 Ohio Department of Transportation crossdrain installation. (11) The tests at California State University – Sacramento utilized a tilting table, a bedload of

crushed quartz, control pH levels of 4 and 7, and corrugated PE pipe, corrugated steel pipe, and reinforced concrete pipe. In one test, with concrete pipe and corrugated PE pipe placed side-by-side on the tilting table, the test was run to first perforation. The thick-walled concrete pipe perforated in about 10 days, while the corrugated polyethylene pipe had a slightly roughened invert, but no perforations. The 1981 Ohio DOT installation carries a substantial bedload of crushed sandstone from an abandoned strip mine. The flow also has had a pH of less than 4. The invert of this pipe is still in excellent condition.

Summary & Conclusions:

1. There is considerable supporting justification for assuming a 100-year or greater design service life for corrugated polyethylene pipe, when properly used and reasonably well installed. Dr. Janson's work (6) is excellent in presenting the support for this position.
2. Minimum material design values for tensile strength and modulus of elasticity are:

| Type of Pipe | Minimum Cell Class ASTM D 3350 | Allowable Long-Term Strain % | Initial F _u min (MPa) | Initial E min (MPa) | 50-Year F _u min (MPa) | 50-Year E min (MPa) | 100-Year F _u min (MPa) | 100-Year E min (MPa) |
|-----------------------------------|-----------------------------------|------------------------------|----------------------------------|---------------------|----------------------------------|---------------------|-----------------------------------|----------------------|
| Corrugated PE Pipe – AASHTO M 294 | 335400C | 5 | 22.75 | 900 | 8.5 | 179 | 7.5 | 174 |

3. The AASHTO Subcommittee on Materials should increase the minimum density to 0.948 gms/cc from the current 0.945 gms/cc.

Attachments & Supporting Documentation:

1. Killough, Dr. James M. "Mike", Senior Chemist Consultant, BP Solvay Polyethylene North America, to Jim Goddard, April 18, 2002.
2. Ayres, R. L., Phillips Chemical Company, to James B. Goddard, August 10, 1984.
3. Janson, Dr. Lars-Eric, "Plastic Pipes for Water Supply and Sewage Disposal," Borealis, Sven Axelsson AB/Affish & Reklamtryck AB, Boras, 1996.
4. Janson, Dr. Lars-Eric, "Plastic Pipes – How Long Can They Last?" Report No. 4, Kontrollradet for Plasttror, November, 1996.
5. Gabriel, Dr. Lester H. & Goddard, James B., "Curved Beam Stiffness for Thermoplastic Gravity-Flow Drainage Pipes," Transportation Research Board, January, 1999.
6. Gabriel, Dr. Lester H. & Goddard, James B., "Relaxation Modulus (from Curved Beam Test & Parallel Plate Test)," Advanced Drainage Systems, Inc., June, 2002.
7. Janson, Dr. Lars-Eric, "Short-Term Versus Long-Term Pipe Ring Stiffness in the Design of Buried Plastic sewer Pipes," VBB Consulting, Ltd., Stockholm, Sweden
8. Elzink, W. J. and Molin, J., "The Actual Performance of Buried Plastics Pipes in Europe Over 25 Years," B. V. Wavin Research and Development, Dedemsvaart, Netherlands.
9. Goddard, James B., "Pennsylvania Deep Burial Study 15 Year Summary Report," Advanced Drainage Systems, Inc., Columbus, Ohio, August, 2002.
10. Sanders, Glen and Ellis, John, "Clogging of Perforations in Plastic Drain Pipe," U. S. Department of the Interior, Bureau of Reclamation, Denver, Colorado, March, 2002.
11. Corrugated Polyethylene Pipe Association, "Chemical & Abrasion Resistance of Corrugated Polyethylene Pipe," 1997.