(Revision Date: March 5, 2001)

# A Comparison of Engineering Considerations for Pressure Pipe

Ductile Iron

Prestressed Concrete Cylinder

Bar-Wrapped Concrete Cylinder

Polyvinyl Chloride (pvc), 4"-12"

Polyvinyl Chloride (pvc),14"-48"

Molecularly Oriented Polyvinyl Chloride (pvco)

Steel

High-Density Polyethylene (hdpe)

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# DUCTILE IRON

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| **Available Sizes** | 3" - 64" |
| **Laying Lengths** | 18', 20' |
| **Standards** | AWWA C104, AWWA C105, AWWA C110, AWWA C111, AWWA C115, AWWA C116, AWWA C150, AWWA C151, AWWA C153, AWWA C600, AWWA C606, ASTM A377, ASTM A674, ASTM A716, ASTM A746 |
| **Pressure Class/Ratings** | Rated up to 350 psi (with an additional 100 psi surge capacity).<br>Pressure Class 150, 200, 250, 300 & 350<br>Higher pressures may be designed. |
| **Method of Design** | Designed as a flexible conduit. Separate design for internal pressure (hoop stress equation) and external load (bending stress and deflection). An allowance for the casting tolerance and service allowance are added to the net thickness. |
| **Internal Pressure Design** | Pressure Class: stress due to working pressure plus surge pressure cannot exceed 50% of the minimum yield strength of 42,000 psi (2.0 safety factor), resulting in a maximum tensile working stress of 21,000 psi. |
| **Surge Allowance** | Included standard surge allowance is 100 psi (based on an instantaneous velocity change of approximately 2 fps), however, actual anticipated surge pressures should be used. |
| **External Load Design** | Earth load uses the prism load with a soil density of 120 pcf. Live load is AASHTO H-20 truck load, assuming a single 16,000 lb. concentrated wheel load. Impact factor is 1.5 for all depths. Ring bending stress limited to 48,000 psi, which is ½ the minimum ultimate bending strength. Deflection is limited to 3% of the outside diameter of the pipe, which is ½ of the deflection that might damage the cement-mortar lining. |
| **Factor of Safety** | **Pressure Design:** 2.0 (including surge) based on minimum tensile yield strength of 42,000 psi.<br>**External Load Design:** 2.0 for bending based on the minimum ultimate ring bending strength of 96,000 psi, or 1.5 for bending based on minimum ring yield bending strength of 72,000 psi. 2.0 for deflection for cement-mortar-lined pipe.<br>**Fatigue Design:** The maximum allowable tensile working stress of 21,000 psi is below the fatigue limit of 28,000 to 35,000 psi for ductile iron. Therefore, ductile iron pipe is not subject to failure due to cyclic stresses.<br>**Note:** Actual safety factors are greater than the nominal safety factors due to the addition of the service allowance and the allowance for the casting tolerance in the design procedure. |
| **Trench Conditions** | Five specified laying conditions (Types 1-5). Conservative E′ (from 150 to 700 psi) and soil strength parameters listed. Type 1(flat bottom, loose backfill) or Type 2 (flat bottom trench, backfill lightly consolidated to centerline of pipe) are adequate for most applications. |
| **Hydrostatic Testing** | Each pipe tested to a minimum of 500 psi for at least 10 seconds at full pressure. |
| **Factory Tests** | At least one sample during each casting period of approximately 3 hours shall be tested for tensile strength and elongation; must show a minimum yield of 42,000 psi, a minimum ultimate of 60,000 psi and minimum elongation of 10%. At least one Charpy impact sample shall be taken per hour (minimum 7 ft-lb) with an additional low-temperature impact test (minimum 3 ft-lb) made from at least 10% of the sample coupons taken for the normal Charpy impact test. |
| **Comments** | Service allowance and an allowance for the casting tolerance are additive to the net pipe wall thickness by design. Realistic E′ values are utilized in the design. Inside diameter exceeds nominal diameter in practically all cases. This allows for greater flow than most substitute pipe materials. Design is not based on performance limits. Overall safety factor is far greater than that used in the design procedure. |

# PRESTRESSED CONCRETE CYLINDER

**Available Sizes**
Lined-Cylinder Pipe (LCP): 16" - 60"
Embedded-Cylinder Pipe (ECP): 24" - 144"+

**Laying Lengths**
16' minimum

**Standards**
AWWA C301, AWWA C304

**Pressure Class/Ratings**
None specified. Pipe designed on a project specific basis.

**Method of Design**
Rigid material; combined stress design (internal and external loads). Limit-states design approach based on conditions that bound structural usefulness. Serviceability, elastic and strength limit-states are addressed so as to achieve an acceptable probability that the limit-state is not exceeded. Cracking is allowed in the concrete core and cement mortar coating under transient conditions.

**Internal Pressure Design**
Maximum working pressure cannot exceed 80% of $P_o$ for LCP or $P_o$ for ECP, where $P_o$ is the decompression pressure that relieves the final prestress in the core concrete. With surge, design pressure cannot exceed 1.2 $P_o$ for LCP, and 1.4 $P_o$ for ECP. Tension in the core concrete is allowed under transient conditions. Tension in the cement-mortar coating is allowed.

**Surge Allowance**
Surge allowance is the greater of 40 psi or 40% of the working pressure.

**External Load Design**
Three limit-states are defined; serviceability, elastic and strength. Thirteen (13) loading conditions and fourteen (14) limiting criteria are used for LCP. Fourteen (14) loading conditions and eighteen (18) limiting criteria are used for ECP. Several of the limiting criteria do allow for cracking in the concrete core and cement mortar coating. Reference is made to AWWA Manual M9 for calculation of earth load. Truck load is HS20 (unless otherwise specified).

**Factor of Safety**
Working pressure design is based on the decompression pressure, $P_o$, at which there is no compressive stress in the core. For LCP the factor of safety with regard to $P_o$ is 1.25. For ECP the factor of safety with regard to $P_o$ is 1.0. Working plus transient pressure design allows the pressure to exceed $P_o$ for both LCP and ECP, thereby allowing the core and protective mortar coating to go into tension.

**Trench Conditions**
Five rigid pipe trench types, R1-R5, considered in design.

**Hydrostatic Testing**
Completed pipe not tested. Steel cylinder is leak-tested to a predetermined stress in the range of 20,000 - 25,000 psi. This equates to a maximum test pressure range of from 18 psi (144-inch pipe) to 166 psi (16-inch pipe) for 16 gauge cylinders.

**Factory Tests**
Tensile test on one coil or bundle of steel sheet per heat. Torsion test on 10% of prestressing wire coils. Leak test on steel cylinder (see above). Concrete test cylinders to verify the 28-day compressive strength of the concrete used in the core. Compressive strength of mortar coating tested every six months.

**Comments**
The design allows for the concrete core and mortar coating to crack, potentially exposing the steel to corrosion. The design also allows the concrete core to go into tension under transient conditions. Joints should be grouted both inside and outside to protect exposed steel from corrosion. Field tapping is difficult. The pipe cannot be cut in the field; special closure pieces are required. Concrete pipe requires special fabrication for each project. Line and grade drawings are required for all installations. Parameters for standard design limitations include maximum time in storage prior to installation, maximum burial time prior to pressurizing, and minimum relative humidity, among others.

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# BAR-WRAPPED CONCRETE CYLINDER

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| **Available Sizes** | 10" - 60" |
| **Laying Lengths** | 32' - 40' |
| **Standards** | AWWA C303 |
| **Pressure Class/Ratings** | Up to 400 psi |
| **Method of Design** | **Design not covered by a standard.** Reference is made to AWWA Manual M9 for design procedures. Semi-rigid (flexible) pipe theory. Separate stress design (internal pressure and external load). Total area of steel (cylinder and bar reinforcement) is used to hold pressure. |
| **Internal Pressure Design** | **Design not covered by a standard.** Reference is made to AWWA Manual M9 for design procedures. The average circumferential stress in the steel cylinder and bar reinforcement is not to exceed 18,000 psi nor 50% of the specified minimum yield strength of the steel used in the cylinder and bar reinforcement. The area of bar reinforcement shall not be greater than 60% of the total area of circumferential reinforcement. |
| **Surge Allowance** | **Design not covered by a standard.** Reference is made to AWWA Manual M9 for design procedures. "Built-in" surge allowance equal to 50% of design operating pressure. If surge pressure is greater than 50% of the design operating pressure then the stress from working pressure plus surge pressure cannot exceed 27,000 psi nor 75% of the tensile yield strength of the steel used in the cylinder and bar reinforcement (resulting in a safety factor of 1.33). |
| **External Load Design** | **Design not covered by a standard.** Reference is made to AWWA Manual M9 for design procedures. Earth load is calculated using the Marston load theory. Live load is AASHTO HS-20 Load (16,000 lbs) or AASHTO Alternate Load (12,000 lbs) assumed to be applied through dual wheel assemblies uniformly distributed over a surface area of 10 inch x 20 inch. Impact factor of 1.3 (for depths of cover less than 1 feet), 1.2 (for depths of cover greater than 1 feet and less than 2 feet), 1.1 (for depths of cover greater than 2 feet and less than 3 feet) or 1.0 (for depths of cover greater than 3 feet). Utilizes the Modified Iowa Deflection Equation. Deflection limited to $D^2/4000$ in., where D is the nominal inside diameter in inches. Stiffness of the pipe in conjunction with the support provided by the surrounding soil is used to counteract external loads. |
| **Factor of Safety** | Safety factor of 2.0 based on working pressure only. Safety factor reduced to as little as 1.33 when surge pressure is considered. |
| **Trench Conditions** | **None specified by a standard.** Four trench types for semirigid pipe (Type S1 - S4) are given in AWWA Manual M9. E′ for the trench types: 200 psi for Type S1, 400 psi for Type S2, 700 psi for Type S3 and 1,000 psi for Type S4. |
| **Hydrostatic Testing** | Completed pipe not tested. Steel cylinder is production-tested to 75% of specified minimum yield strength (22,500 psi for the minimum 30 ksi steel) This equates to a maximum test pressure range of from 243 psi (10-inch pipe, 16 gauge cylinder) to 98 psi (60-inch pipe, 10 gauge cylinder). |
| **Factory Tests** | Weld tests on steel cylinder only. Concrete cylinders must have a minimum compressive strength of 4,500 psi in 28 days. Absorption test performed on samples of cured mortar from each shift. Average absorption shall not exceed 9%. |
| **Comments** | This is a composite material pipe, which is greatly dependent on proper interaction and manufacture of the component materials. Hydrostatic shop tests of the completed pipe which might reveal weakness in the form of coating cracks are not conducted. Joints should be grouted both inside and outside to protect exposed steel from corrosion. Difficult to cut or tap the pipe in the field. Line and grade drawings are required for all installations. |

# POLYVINYL CHLORIDE (PVC), 4" - 12"

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| **Available Sizes** | 4" - 12" |
| **Laying Lengths** | 20' |
| **Standards** | AWWA C900, AWWA C605 |
| **Pressure Class/Ratings** | Pressure Class 100, 150 & 200 (DRs 25, 18 & 14 respectively) at a service temperature of 73.4˚F. For service temperatures greater than 73.4˚F, the pressure classes must be appropriately reduced. |
| **Method of Design** | Designed as a flexible conduit. Separate design for internal pressure (hoop stress equation) and external load (deflection) - **external load design is not covered by a standard.** No consideration for bending stress. |
| **Internal Pressure Design** | Pressure Class: stress due to working pressure plus surge pressure cannot exceed the Hydrostatic Design Basis (HDB) of 4,000 psi ÷ 2.5 safety factor, resulting in a Hydrostatic Design Stress (HDS) of 1,600 psi. |
| **Surge Allowance** | 30, 35 or 40 psi surge allowance for DRs 25, 18 & 14 respectively. Based on an instantaneous velocity change of approximately 2 fps. |
| **External Load Design** | **Design not covered in the standard.** Reference is made to AWWA M23 for design procedures. Marston earth load or prism load is used. Live load is taken as AASHTO H-20, assuming two 16,000 lb. wheel loads 6 feet apart with contact patches of 18-by-20 inches. Considered for depths of cover of "usually 4 feet and less." Impact factor not discussed. Utilizes the Modified Iowa Deflection Equation, however, provides no deflection limits for design and defines no safety factors. |
| **Factor of Safety** | **Pressure Design:** 2.5 (including surge) based on HDB. To qualify for an HDB of 4,000 psi, the actual HDB of the material may be as low as 3,830 psi in accordance with ASTM D2837. Thus, the safety factor may be lower than the nominal used in design.<br>**External Load Design:** No safety factors can be calculated. No criteria are defined.<br>**Fatigue Design:** The Hydrostatic Design Stress of 1,600 psi exceeds the fatigue limit of 1,500 psi. Therefore, AWWA C900 pvc is subject to failure due to cyclic stresses.<br>**Note:** Safety factors and strength greatly affected by temperatures, surface scratches, and extended exposure to sunlight. Pipes under cyclic loading likely have lower safety factors than those under static loading. |
| **Trench Conditions** | **Not covered in the standard.** The Foreword of the standard references AWWA M23 and ANSI/AWWA C605. ANSI/AWWA C605 contains five trench conditions referred to as "common embedment types." These trench types are copies of the trench types used in the Ductile Iron pipe design standard (AWWA C150), however, AWWA C605 uses much less conservative trench values for the bedding constant (K) and soil modulus (E′) for the most commonly specified trench types used for pvc pipe (Types 4 and 5). Therefore, proper bedding procedures are critical with pvc pipe to achieve adequate support for the pipe. |
| **Hydrostatic Testing** | Each pipe tested to 4 times the designated pressure class for at least 5 seconds at full pressure. There is a provision (Section 5.1.14) for the "purchaser or supplier" to allow the manufacturer to conduct hydrostatic proof tests for pipes at test frequencies other than the requirements stated. In other words, **not every piece of pvc pipe "must" be pressure tested.** |
| **Factory Tests** | Sustained pressure test (1,000 hour) is run semiannually at approximately 3.25 - 3.5 times the pressure class. Quick burst strength (at approximately 5 times the pressure class) tested once every 24 hours. Flattening resistance tested once every 8 hours (ASTM D2412). Extrusion quality tested once every 8 hours (ASTM D2152). |
| **Comments** | Potential problems include lower flow capacity, cold flow, temperature changes, cyclic loading, storage, tapping, floatation, difficulty in locating, solvent attack, hydrocarbon permeation, thawing and installation. Some of the most serious potential problems are over-deflection and splitting the pipe by direct tapping. Special care must be exercised such that future excavations do not cause costly and disruptive damage to the pipe. |

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# POLYVINYL CHLORIDE (PVC), 14" - 48"

**Available Sizes** 14" - 48"

**Laying Lengths** 20'

**Standards** AWWA C905, AWWA C605

**Pressure Class/Ratings** Pressure rated at 80, 100, 125, 160, 165, 200, 235 & 300 psi (DRs 51, 41, 32.5, 26, 25, 21, 18 & 14 respectively) at a service temperature of 73.4˚F. For service temperatures greater than 73.4˚F, the pressure ratings must be appropriately reduced.

**Method of Design** Designed as a flexible conduit. Separate design for internal pressure (hoop stress equation) and external load (deflection) - **external load design is not covered by a standard.** No consideration for bending stress.

**Internal Pressure Design** Pressure Rating: stress due to working pressure cannot exceed the Hydrostatic Design Basis (HDB) of 4,000 psi ÷ 2.0 safety factor, resulting in a Hydrostatic Design Stress (HDS) of 2,000 psi.

**Surge Allowance** **None included.** Pressure Ratings must be reduced to allow for pressure surges. Pressure surges based on an instantaneous velocity change of 2 fps would be 21, 23, 26, 29, 30, 32, 35 & 40 psi (for DRs 51, 41, 32.5, 26, 25, 21, 18 & 14 respectively).

**External Load Design** **Design not covered in the standard.** Reference is made to AWWA M23 for design procedures. Marston earth load or prism load is used. Live load is taken as AASHTO H-20, assuming two 16,000 lb. wheel loads 6 feet apart with contact patches of 18-by-20 inches. Considered for depths of cover of "usually 4 feet and less." Impact factor not discussed. Utilizes the Modified Iowa Deflection Equation, however, provides no deflection limits for design and defines no safety factors.

**Factor of Safety** **Pressure Design:** 2.0 (no surge included) based on HDB. Section 4.6.2 cautions that when AWWA C905 pipe sizes are used in distribution systems that the safety factor may need to be set at 2.5 and an allowance for surge pressure may need to be added. If a surge pressure, based on an instantaneous velocity change of 2 fps, is included, the safety factor could be as low as 1.58 to 1.76 (for DRs 51 & 14 respectively). Additionally, to qualify for an HDB of 4,000 psi, the actual HDB of the material may be as low as 3,830 psi in accordance with ASTM D2837. Thus, the safety factor may be further reduced.
**External Load Design:** No safety factors can be calculated. No criteria are defined.
**Fatigue Design:** The Hydrostatic Design Stress of 2,000 psi exceeds the fatigue limit of 1,500 psi. Therefore, AWWA C905 pvc is subject to failure due to cyclic stresses.
**Note:** Safety factors and strength greatly affected by temperatures, surface scratches, and extended exposure to sunlight. Pipes under cyclic loading likely have lower safety factors than those under static loading.

**Trench Conditions** **Not covered in the standard.** The Foreword of the standard references AWWA M23 and ANSI/AWWA C605. ANSI/AWWA C605 contains five trench conditions referred to as "common embedment types." These trench types are copies of the trench types used in the Ductile Iron pipe design standard (AWWA C150), however, AWWA C605 uses much less conservative trench values for the bedding constant (K) and soil modulus (E′) for the most commonly specified trench types used for pvc pipe (Types 4 and 5) Therefore, proper bedding procedures are critical with pvc pipe to achieve adequate support for the pipe.

**Hydrostatic Testing** Each pipe tested to 2 times the designated pressure rating (less than half of that used for AWWA C900 pvc) for at least 5 seconds at full pressure. There is a provision (Section 5.1.9) for the "purchaser or supplier" to allow the manufacturer to conduct hydrostatic proof tests for pipes at test frequencies other than the requirements stated. In other words, **not every piece of pvc pipe "must" be pressure tested.**

**Factory Tests** Flattening resistance tested once every 8 hours (ASTM D2412). Extrusion quality tested once every 8 hours (ASTM D2152). **Quick burst and sustained pressure tests are not required.**

**Comments** Pvc is vulnerable to buckling in certain situations. Other potential problems include lower flow capacity, cold flow, temperature changes, cyclic loading, storage, tapping, floatation, difficulty in locating, solvent attack, hydrocarbon permeation, thawing and installation. Some of the most serious potential problems are over-deflection and splitting the pipe by tapping. Special care must be exercised such that future excavations do not cause costly and disruptive damage to the pipe.

# MOLECULARLY ORIENTED POLYVINYL CHLORIDE (PVCO)

**Available Sizes** 4" - 12"

**Laying Lengths** 20'

**Standards** AWWA C909, AWWA C605

**Pressure Class/Ratings** Pressure Class 100, 150 & 200 at a service temperature of 73.4˚F. For service temperatures greater than 73.4˚F, the pressure classes must be appropriately reduced.

**Method of Design** Designed as a flexible conduit. Separate design for internal pressure (hoop stress equation) and external load (deflection) - **external load design is not covered by a standard.** No consideration for bending stress.

**Internal Pressure Design** Pressure Class: stress due to working pressure plus surge pressure cannot exceed the Hydrostatic Design Basis (HDB) of 7,100 psi ÷ 2.5 safety factor, resulting in a Hydrostatic Design Stress (HDS) of 2,840 psi.

**Surge Allowance** 23, 27 or 31 psi surge allowance for Pressure Class 100, 150 & 200 respectively. Based on an instantaneous velocity change of approximately 2 fps.

**External Load Design** **Design not covered in the standard.** Reference is made to AWWA M23 for design procedures. Marston earth load or prism load is used. Live load is taken as AASHTO H-20, assuming two 16,000 lb. wheel loads 6 feet apart with contact patches of 18-by-20 inches. Considered for depths of cover of "usually 4 feet and less." Impact factor not discussed. Utilizes the Modified Iowa Deflection Equation, however, provides no deflection limits for design and defines no safety factors.

**Factor of Safety** **Pressure Design:** 2.5 (including surge) based on HDB. To qualify for an HDB of 7,100 psi, the actual HDB of the material may be as low as 6,810 psi in accordance with ASTM D2837. Thus, the safety factor may be lower than the nominal used in design.
**External Load Design:** No safety factors can be calculated. No criteria are defined.
**Fatigue Design:** The fatigue limit of pvco has not been reported. AWWA C900 pvc and AWWA C905 pvc are both subject to fatigue failure.
**Note:** Safety factors and strength greatly affected by temperatures, surface scratches, and extended exposure to sunlight. Pipes under cyclic loading likely have lower safety factors than those under static loading.

**Trench Conditions** **Not covered in the standard.** The Foreword and Appendix A of the standard reference AWWA M23 and ANSI/AWWA C605. ANSI/AWWA C605 contains five trench conditions referred to as "common embedment types." These trench types are copies of the trench types used in the Ductile Iron pipe design standard (AWWA C150), however, AWWA C605 uses much less conservative trench values for the bedding constant (K) and soil modulus (E′) for the most commonly specified trench types used for pvc pipe (Types 4 and 5) Therefore, proper bedding procedures are critical with pvco pipe to achieve adequate support for the pipe.

**Hydrostatic Testing** Each pipe tested to 4 times the designated pressure class for at least 5 seconds at full pressure. There is a provision (Section 5.1.9) for the "purchaser or supplier" to allow the manufacturer to conduct hydrostatic proof tests for pipes at test frequencies other than the requirements stated. In other words, **not every piece of pvc pipe "must" be pressure tested.**

**Factory Tests** Sustained pressure test (1,000 hour) is run semiannually at approximately 3.25 - 3.5 times the pressure class. Quick burst strength (at about 5 times the pressure class) tested once every 24 hours. Flattening resistance tested once every 8 hours (ASTM D2412). Extrusion quality tested once every 8 hours (ASTM D2152).

**Comments** All taps on pvco pipe must use saddles. Other potential problems include cold flow, temperature changes, cyclic loading, storage, floatation, difficulty in locating, solvent attack, hydrocarbon permeation, thawing, installation and over-deflection. Special care must be exercised such that future excavations do not cause costly and disruptive damage to the pipe. Additionally, it has been advertised that "pvco pipe's inside diameter is larger than Ductile Iron, providing greater flow capacity and lower head loss." This statement is not correct for all pvco pipe. Ductile Iron actually has a larger inside diameter than 8-inch PC200, 10-inch PC150, 10-inch PC200, 12-inch PC150 and 12-inch PC200 pvco pipe. Additionally, a Hazen-Williams "C" factor of 150 is promoted for use with pvc and pvco pipe, however, DIPRA has conducted flow tests comparing Ductile Iron to pvc pipe with an average *measured* Hazen-Williams "C" factor or 139.53 for pvc pipe.

# STEEL

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| **Available Sizes** | 6" and larger |
| **Laying Lengths** | Variable, commonly up to 45' |
| **Standards** | AWWA C200, AWWA C203, AWWA C205, AWWA C206, AWWA C207, AWWA C208, AWWA C209, AWWA C210, AWWA C213, AWWA C214, AWWA C215, AWWA C216, AWWA C217, AWWA C218, AWWA C222 |
| **Pressure Class/Ratings** | **Not covered in the standard** - determined by specifications/manufacturer. |
| **Method of Design** | **No design standard (internal pressure or external load) for steel pipe.** Reference is made in the Foreword of AWWA C200 to AWWA Manual M11, *Steel Pipe - A Guide For Design and Installation*, for determination of wall thickness. Designed as a flexible conduit. Separate design for internal pressure (hoop stress equation) and external load (deflection). No consideration for bending stress. |
| **Internal Pressure Design** | **Not covered by a standard.** Barlow cylinder equation is used. Stress from working pressure cannot exceed 50% of tensile yield strength. Explicit surge pressure is not directly incorporated into the design pressure. |
| **Surge Allowance** | "Built-in" surge allowance equal to 50% of design operating pressure. If surge pressure is greater than 50% of the design operating pressure then the stress from working pressure plus surge pressure cannot exceed 75% of the tensile yield strength. Safety factor is reduced to as low as 1.33 when surge pressures occur. |
| **External Load Design** | Standard trenches use the Marston earth load equation; embankments or wide trenches use the prism earth load equation. Deflection limited to 2% - 5%, depending on lining and coating. Ring bending stress not considered. Deflection lag factor of 1.0 to 1.5 is used. Buckling is considered. Live load is considered only when expected. No Impact factor given. |
| **Factor of Safety** | **Pressure Design:** Safety factor of 2.0 based on working pressure only. Safety factor reduced to as little as 1.33 when surge pressure is considered. AWWA C200 allows "defects" (Section 4.2.2) of up to 12.5% of the nominal wall thickness and mill tolerance (Section 4.7.3) of up to 0.01 inches (minus tolerance) without accounting for them. Safety factors can approach 1 when surge pressure, defect allowance and mill tolerance are considered.<br>**External Load Design:** Safety factor for external loads not readily determined due to material creep with time. |
| **Trench Conditions** | Class C1, C2, or C3 backfill with specified dry soil densities of 95%-85% respectively. |
| **Hydrostatic Testing** | Each pipe tested to 75% of the specified minimum yield point. |
| **Factory Tests** | Tensile specimens taken from various size lots in accordance with the specified ASTM standard. |
| **Comments** | Safety factor on total internal pressure design can approach 1 when surge pressure, defect allowance and mill tolerance are considered. External load design may be dependent on achieving high E′ values. Line and grade drawings are required for most projects. |

# HIGH-DENSITY POLYETHYLENE (HDPE)

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| **Available Sizes** | 4" - 63" |
| **Laying Lengths** | Variable |
| **Standards** | AWWA C906 |
| **Pressure Class/Rating** | Dependent upon material code: 40 - 198 psi for PE 2406 or PE 3406; 51 - 254 psi for PE 3408. Rated up to 254 psi for 20-inch diameter and smaller. Due to manufacturers limited extrusion capabilities for wall thicknesses greater than 3-inches, ratings may be progressively reduced with increasing sizes greater than 20-inches in diameter. |
| **Method of Design** | Flexible material; internal pressure design only. **External load design is not covered by a standard.** |
| **Internal Pressure Design** | Pressure **Rating:** Stress due to working pressure cannot exceed the Hydrostatic Design Basis (HDB) of 1,600 psi ÷ 2.0 safety factor, resulting in a Hydrostatic Design Stress (HDS) of 800 psi for PE 3408. **Any surge pressure compromises the safety factor.** |
| **Surge Allowance** | **Not included.** Surge pressures are allowed to compromise the "Design Factor" which results in a safety factor below 2.0. |
| **External Load Design** | **None discussed in standard.** |
| **Factor of Safety** | A "Design Factor" is used in the internal pressure design formula. This factor is simply the inverse of the more common "Safety Factor." This "Design Factor," in reality, is not a constant number. The design formula for hdpe pipe ignores surge pressures by merely increasing the "Design Factor," thereby, reducing the "Safety Factor," to compensate for them. **Ignoring surge pressures, the "Design Factor" is 0.5 ("Safety Factor" is 2.0). Acknowledging surge pressures, the "Design Factor" is greater than 0.5 ("Safety Factor" is less than 2.0).** Additionally, to qualify for an HDB of 1,600 psi, the actual HDB of the material may be as low as 1,530 psi in accordance with ASTM D2837. Thus, the "Safety Factor" may be lower than the nominal used in design. |
| **Trench Conditions** | **None.** |
| **Hydrostatic Testing** | Only one pipe size from three size ranges (4- to 12-, 14- to 20-, and greater than 24-inch) are subjected to an elevated temperature sustained-pressure test **semiannually.** Also, only one pipe per production run **may be** subject to a quick burst test (a ring tensile test or a five-second pressure test can be substituted for this test). |
| **Factory Tests** | Bend-back or elongation-at-break test; once per production run. Ring tensile, quick burst test, or five second pressure test; once per production run. Melt-flow index; once per day. Density; once per day. Carbon black content; once per production run. |
| **Comments** | No specified external load design model is recommended. Some manufacturer's literature indicates external design should incorporate E′ values of 1,000 psi or greater. Internal pressure design is based on hydrostatic design basis (HDB) with the recommended HDB assumed at 73.4˚F. The HDB must be adjusted downward for temperatures in excess of 80˚F. The "Design Factor" is relied upon to compensate for occasional surges up to twice the "pressure class", and recurring surges not to exceed 1.5 times the "pressure class". No explicit surge allowance is used in design, as surges are allowed to temporarily compromise the factor of safety. Although referred to as a "pressure class", under generally accepted definitions, hdpe pipe would actually be a "pressure rated" pipe due to the lack of an explicit surge allowance in design. Due to the very thick walls of hdpe pipe, the inside diameter is typically much smaller than the nominal pipe size - **hdpe pipe must often be upsized to meet hydraulic requirements**. |