Designation: F 1759 – 97 (Reapproved 2004)

An American National Standard

# Standard Practice for Design of High-Density Polyethylene (HDPE) Manholes for Subsurface Applications[1]

## 1. Scope

1.1 This practice covers general and basic procedures related to the design of manholes and components manufactured from high-density polyethylene (HDPE) for use in subsurface applications and applies to personnel access structures. The practice covers the material, the structural design requirements of the manhole barrel (also called vertical riser or shaft), floor (bottom), and top, and joints between shaft sections.

1.2 This practice offers the minimum requirements for the proper design of an HDPE manhole. Due to the variability in manhole height, diameter, and the soil, each manhole must be designed and detailed individually. When properly used and implemented, this practice can help ensure a safe and reliable structure for the industry.

1.3 *Disclaimer*—The reader is cautioned that independent professional judgment must be exercised when data or recommendations set forth in this practice are applied. The publication of the material contained herein is not intended as a representation or warranty on the part of ASTM that this information is suitable for general or particular use, or freedom from infringement of any patent or patents. Anyone making use of this information assumes all liability arising from such use. The design of structures is within the scope of expertise of a licensed architect, structural engineer, or other licensed professional for the application of principles to a particular structure.

1.4 The values stated in inch-pound units are to be regarded as the standard. The SI units given in parentheses are provided for information only.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

## 2. Referenced Documents

2.1 *ASTM Standards:* [2]

D 653 Terminology Relating to Soil, Rock, and Contained Fluids
D 1600 Terminology for Abbreviated Terms Relating to Plastics
D 2321 Practice for Underground Installation of Thermoplastic Pipe for Sewers and Other Gravity-Flow Applications
D 2657 Practice for Heat Fusion Joining of Polyolefin Pipe and Fittings
D 2837 Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials or Pressure Design Basis for Thermoplastic Pipe Products
D 3035 Specification for Polyethylene (PE) Plastic Pipe (DR-PR) Based on Controlled Outside Diameter
D 3212 Specification for Joints for Drain and Sewer Plastic Pipes Using Flexible Elastomeric Seals
D 3350 Specification for Polyethylene Plastics Pipe and Fittings Materials
F 412 Terminology Relating to Plastic Piping Systems
F 477 Specification for Elastomeric Seals (Gaskets) for Joining Plastic Pipe
F 714 Specification for Polyethylene (PE) Plastic Pipe (SDR-PR) Based on Outside Diameter
F 894 Specification for Polyethylene (PE) Large Diameter Profile Wall Sewer and Drain Pipe

## 3. Terminology

3.1 *Definitions:*

3.1.1 Definitions used in this practice are in accordance with Terminology F 412 and Terminology D 1600 unless otherwise indicated.

3.2 *Definitions of Terms Specific to This Standard:*

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[1] This practice is under the jurisdiction of ASTM Committee F17 on Plastic Piping Systems and is the direct responsibility of Subcommittee F17.26 on Olefin Based Pipe.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3.2.1 *anchor connection ring*—an HDPE ring attached to the manhole riser on which to place an antiflotation device, such as a concrete anchor ring.

3.2.2 *arching*—mobilization of internal shear resistance within a soil mass that results in a change in soil pressure acting on an underground structure.

3.2.3 *benching*—the internal floor of a manhole when it is elevated above the manhole invert, usually provided as a place for personnel to stand.

3.2.4 *closed profile*—a manhole barrel construction that presents an essentially smooth internal surface braced with projections or ribs, which are joined by an essentially smooth outer wall. Solid wall construction is considered a special case of the closed profile.

3.2.5 *downdrag*—downward shear force acting on the shaft's external surface and resulting from settlement of the manhole backfill.

3.2.6 *extrusion welding*—a joining technique that is accomplished by extruding a molten polyethylene bead between two prepared surface ends.

3.2.7 *floor*—the lowest internal surface of the manhole. The floor and bottom are often the same.

3.2.8 *inlet/outlet*—pipe (conduit) passing through the wall of the manhole.

3.2.9 *invert*—the flow channel in the floor of a manhole. This may consist of the lower half of a pipe, thus the name "invert".

3.2.10 *manhole*—an underground service access structure, which can access pipelines, conduits, or subsurface equipment.

3.2.11 *manhole bottom*—the lowest external surface of the manhole.

3.2.12 *manhole cone*—the top portion of the manhole through which entrance to the manhole is made and where the diameter may increase from the entrance way to the larger manhole barrel. Sometimes referred to as the *manway reducer.*

3.2.13 *open profile*—a manhole barrel construction that presents an essentially smooth internal surface with a ribbed or corrugated external surface. Open profile barrel constructions are normally *not* used for manholes.

3.2.14 *performance limits*—mechanisms by which the function of a structure may become impaired.

3.2.15 *riser*—the vertical barrel or "shaft" section of a manhole.

3.3 See Fig. 1 for illustration of manhole terminology.

## 4. Significance and Use

4.1 *Uses*—The requirements of this practice are intended to provide manholes suitable for installation in pipeline or conduit trenches, landfill perimeters, and landfills with limited settlement characteristics. Direct installation in sanitary landfills or other fills subject to large (in excess of 10 %) soil settlements may require special designs outside the scope of this practice.

4.1.1 Manholes are assumed to be subject to gravity flow only.

4.2 *Design Assumption*—The design methodology in this practice applies only to manholes that are installed in backfill consisting of Class I, Class II, or Class III material as defined in Practice D 2321, which has been compacted to a minimum of 90 % standard proctor density. The designs are based on the backfill extending at least 3.5 ft (1 m) from the perimeter of the manhole for the full height of the manhole and extending laterally to undisturbed in situ soil. Manholes are assumed placed on a stable base consisting of at least 12 in. (30.5 cm) of Class I material compacted to at least 95 % standard proctor density or a concrete slab. The foundation soils under the base must provide adequate bearing strength to carry downdrag loads.

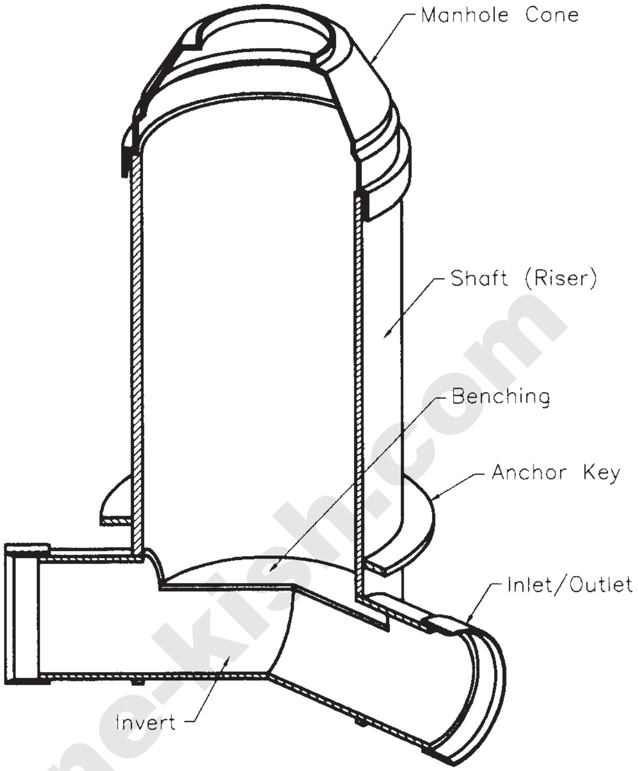

FIG. 1 Manhole Terminology

4.2.1 Manholes installed in sanitary landfills or other fills experiencing large settlements may require special designs beyond the scope of this practice. The designer should evaluate each specific site to determine the suitability for use of HDPE manholes and the designer should prepare a written specification for installation, which is beyond the scope of this practice.

## 5. Materials

5.1 *HDPE Material*—Manhole components, such as the riser, base, and anchor connection ring, shall be made of HDPE plastic compound having a cell classification of 334433C or higher, in accordance with Specification D 3350.

NOTE 1—Materials for use in manholes may be subjected to significant tensile and compressive stresses. The material must have a proven capacity for sustaining long-term stresses. There are no existing ASTM standards that establish such a stress rating except for Test Method D 2837. Work is currently in progress to develop an alternate method for stress rating materials and when completed, this standard will be altered accordingly.

5.2 *Other Material*—Manhole components, such as tops and lids, may be fabricated from materials other than HDPE as long as agreed to by the user and manufacturer.

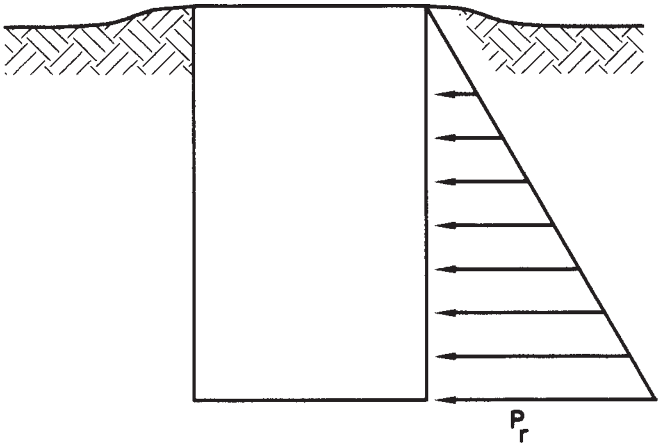

FIG. 2 Radial Pressure Acting on Manhole (Assumed Distribution for Design)

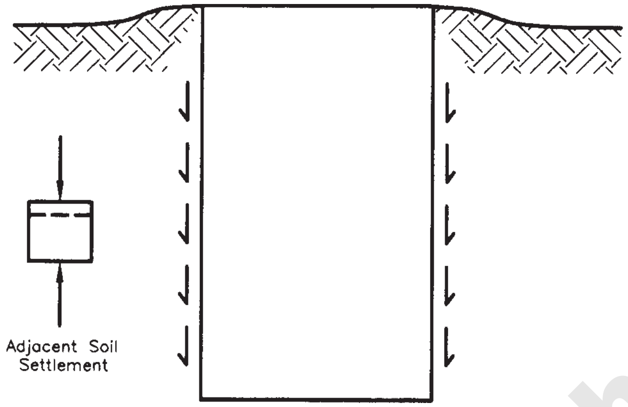

FIG. 3 Downdrag Force Acting on Manhole (Assumed for Design)

## 6. Subsurface Loading on Manhole Riser

6.1 *Performance Limits*—The manhole riser's performance limits include ring deflection, ring (hoop) and axial stress (or strain), and ring and axial buckling. Radially directed loads acting on a manhole cause ring deformation and ring bending stresses. The radial load varies along the length of the manhole. See Fig. 2. In addition to radial stresses, considerable axial stress may exist in the manhole wall as a result of "downdrag". Downdrag occurs as the backfill soil surrounding the manhole consolidates and settles. Axial load is induced through the frictional resistance of the manhole to the backfill settlement. See Fig. 3. The manhole must also be checked for axial compressive stress and axial buckling due to downdrag forces.

6.2 *Earth Pressure Acting on Manhole Riser*:

6.2.1 *Radial Pressure*—Radial pressure along the length of the manhole riser may be calculated using finite element methods, field measurements, or other suitable means. See Hossain and Lytton **(1)**.[3] In lieu of the preceding, the active earth pressure modified for uneven soil compaction around the perimeter of the riser can be used.

NOTE 2—Use of the active pressure is based on measurements taken by Gartung et al. **(2)** and on the ability of the material placed around the manhole to accept tangential stresses and thus relieve some of the lateral pressure. It may actually understate the load on the manhole, however this appears to be offset by the stress relaxation that occurs in the HDPE manhole as shown by Hossain **(3)**. Stress relaxation permits mobilization of horizontal arching, thus the active earth pressure can be assumed for design purposes.

6.2.1.1 If the active earth pressure is modified to take into account uneven compaction around the perimeter of the pipe as described by Steinfeld and Partner **(4)**, the radially directed design pressure is given by Eq 1.

$$P_R = 1.21\,K_A \gamma H \tag{1}$$

where:

$P_R$ = applied radial pressure, psf (KPa),
$\gamma$ = soil unit weight, lbs/ft$^3$(kN/m$^3$),
$H$ = weight of fill, ft (m), and
$K_A$ = active earth pressure coefficient as given by Eq 2.

$$K_A = \tan^2\left(45 - \frac{\phi}{2}\right) \tag{2}$$

where:

$\phi$ = angle of internal friction of manhole embedment material, °.

6.2.2 *Downdrag (Axial Shear Stress)*—The settlement of backfill material surrounding a manhole riser develops a shear stress between the manhole and the fill, which acts as "downdrag" along the outside of the manhole. The settling process begins with the first lift of fill placed around the manhole and continues until all the fill is placed and consolidated. As fill is placed around a manhole, the axial force coupled into the manhole by downdrag shear will increase until it equals the frictional force between the soil and manhole. When this limit is reached, slippage of the fill immediately adjacent to the manhole occurs. This limits the axial force to the value of the frictional force.

6.2.2.1 Downdrag loads can be calculated using finite element methods, field measurements, or other procedures. In lieu of these, the following method may be used. The average shear stress is given by Eq 3, for an active earth pressure distribution as shown in Fig. 2.

$$T_A = \mu\left[\frac{P_{R1} + P_{R2}}{2}\right] \tag{3}$$

where:

$T_A$ = average shear (frictional) stress, psf (kPa),
$P_{R1}$ = radial earth pressure at top of manhole, psf (kPa),
$P_{R2}$ = radial earth pressure at bottom of manhole, psf (kPa), and
$\mu$ = coefficient of friction between manhole and soil.

6.2.2.2 The coefficient of friction between an HDPE manhole with an essentially smooth outer surface and a granular or granular-cohesive soil can be taken as 0.4. See Swan et al. **(5)** and Martin et al. **(6)**. In some applications the coefficient of friction may be reduced by coating the exterior of the manhole with bentonite or some other lubricant.

NOTE 3—The use of external stiffeners or open profiles to stiffen the riser greatly increases the downdrag load due to their impeding the settlement of soil beside the manhole. This has the effect of increasing the

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[3] The boldface numbers given in parentheses refer to a list of references at the end of the text.

average shear stress in Eq 3. Where open profiles are used, the coefficient of friction may equal or exceed 1.0.

6.2.2.3 The downdrag creates an axial-directed load (downdrag load) in the manhole wall that increases with depth. The axial force developed on the manhole can be found by integrating the shear stress (or frictional stress) between the manhole and soil over the height of the fill. This integration is equal to the product of the surface area of the manhole times the average shear stress acting on the surface. The maximum downdrag force can be found using Eq 4. Whether or not to include surface vehicular loads in this term depends on the manhole top design. See 7.3.

$$P_D = T_A \pi \left(\frac{D_o}{12}\right) H \tag{4}$$

where:
$P_D$ = downdrag load, lb (kN),
$D_o$ = outside diameter of manhole, in. (m),
$T_A$ = average shear stress, psf (kPa), and
$H$ = height of fill, ft (m).

NOTE 4—When SI units are used, the 12 in the denominator of Eq 4 may be dropped.

NOTE 5—This equation can be used for HDPE manholes with the recognition that the HDPE manhole is not unyielding. Axial deflection of the HDPE manhole will lessen the downdrag load. The actual load will depend on the relative stiffness between the manhole and the soil and on the effect of stress relaxation properties on the relative stiffness.

6.3 *Groundwater Effects*:

6.3.1 The presence of groundwater around a manhole exerts an external hydrostatic pressure on the riser as well as a buoyant uplift force on the bottom of the manhole. When soil is submerged beneath the groundwater level, the radial earth pressure acting around the outside diameter of the riser is reduced because the buoyant force of the water reduces the effective weight of the soil. In order to calculate the radial pressure acting on the manhole, the groundwater pressure is added to the radial soil pressure produced by the buoyant weight of the soil. The resulting radial pressure is used when calculating ring performance limits. For axial performance limits that are controlled by downdrag forces, the radial pressure should be calculated as though there was no groundwater, since downdrag forces may occur during construction or otherwise prior to submergence.

6.3.2 *Radial Pressure with Groundwater*—The radial pressure acting in a saturated soil can be calculated using finite element methods, field measurements, or other procedures. In lieu of these, Eq 5 can be used to find the radial pressure in a fully saturated fill surrounding the manhole. (Fully saturated means that the groundwater level is at the ground surface but not above it.)

$$P_R{}' = \gamma_W H + 1.21\, K_A\, (\gamma_S - \gamma_W) H \tag{5}$$

where:
$P_R{}'$ = applied radial pressure, psf (kPa),
$K_A$ = active earth pressure coefficient,
$H$ = height of fill, ft (m),
$\gamma_W$ = unit weight of water, pcf (kN/m$^3$), and
$\gamma_S$ = unit weight of saturated soil, pcf (kN/m$^3$).

6.3.3 Where partial saturation of the soil exists, that is where the groundwater level is below the ground surface but above the manhole invert, the radial pressure can be found by combining the pressure due to the soil above the groundwater level and the pressure given in Eq 5 due to the groundwater and the submerged soil. In this case, $H'$ as given in Eq 6 should be substituted for $H$ in Eq 5. See Appendix X2.

$$H' = H - Z \tag{6}$$

where:
$H$ = weight of manhole, ft (m), and
$Z$ = distance to water from surface grade, ft (m).

6.3.4 Radial pressure obtained with Eq 5 should not be used to calculate downdrag pressure as the groundwater does not carry shear and thus does not contribute to downdrag. Calculate downdrag forces assuming a dry installation using Eq 1 for radial pressure as described in 6.2.1. Use either the dry weight or the saturated weight of the soil. The saturated weight applies where the groundwater might be drawn down rapidly.

6.3.5 Where manholes are located beneath the groundwater level, consideration should be given to restraining the manhole to prevent flotation. The groundwater exerts a force on the manhole equal to the weight of the water it displaces. Restraint is provided by downward-resisting forces, which include the weight of the manhole and the downdrag load. However, the full downdrag load given by Eq 4 may not develop, as this force may be reduced due to buoyancy. Therefore, it may be necessary to anchor the manhole to a concrete base or ring. When a ring is used, the buoyant weight of the column of soil projecting above the ring can be added to the resisting force and downdrag is neglected. Axial loads in the manhole riser are minimized by keeping the ring close to the manhole base.

## 7. Design Procedure for HDPE Manholes

7.1 The typical manhole consists of the vertical riser, a floor, a top, and outlets. Each of these components has unique design requirements. The riser must resist groundwater pressure, radial earth pressure, and shear forces due to downdrag induced by settlement of the surrounding soil. It also has to carry the live and dead load weight. The floor has primarily to resist groundwater pressure. The top must transmit live load to the riser. For manholes subjected to vehicular loading, special consideration must be given. See 7.3. Consideration must be given to the attachment of outlets above the invert of the manhole so that they do not induce unduly high bending moments or shear stresses into the riser wall. The load on outlets due to fill settlement increases with the distance the outlets are located above the manhole base.

7.1.1 The manhole riser, floor (bottom), and cone can be designed using finite element analysis, empirical testing, or other means. In lieu of these methods, the methodology given in 7.1-7.3 may be used. This methodology is based on practical experience and field observations and it accounts for arching and viscoelastic effects empirically. Further refinements of this methodology could be made by the following: accounting in a direct way for the earth load reductions due to radial and axial deformations in the manhole structure as a result of the viscoelasticity of the HDPE and the surrounding soil, accounting directly for the benefits of stress relaxation in the HDPE, considering the interaction between axial and ring buckling, and directly determining the soil's enhancement of the riser's axial buckling resistance.

7.1.1.1 *Manhole Riser Design*—Design of the manhole riser consists primarily of assuming a trial wall section and checking its performance limits for the radial and downdrag loads. Usually, the maximum loads occur near the deepest buried portion of the manhole. Because loads are lower near the surface, the riser wall thickness can be tapered from bottom to top.

7.1.1.2 *Radial Loads*—The performance limits under radial loads consist of ring compressive thrust, ring bending, and ring buckling. Ring compression and ring bending create a combined strain in the manhole wall that must be within a limiting strain value.

7.1.1.3 *Ring Compressive Thrust*—Radial loads acting on the manhole create a compressive hoop thrust. For a vertical riser, the maximum thrust occurs at the deepest section. (Due to the presence of the manhole floor, the maximum thrust actually occurs slightly above the floor.) Eq 7 gives the ring thrust.

$$N_T = \frac{P_R}{144} (R_M) \tag{7}$$

where:

$N_T$ = ring thrust, lb/in. (N/cm),
$P_R$ = applied radial pressure, psf (N/cm$^2$) (1N/cm$^2$ = 10 kPa), and
$R_M$ = mean radius of manhole, in. (cm).

For applied radial pressure use Eq 1, if dry, and Eq 5 if groundwater is present.

NOTE 6—When SI units are used, the 144 in the denominator of Eq 7 may be dropped.

7.1.1.4 The ring compressive strain due to the ring thrust is given by Eq 8. In order to calculate the ring compressive strain, a wall section must be assumed.

$$\epsilon_T = \frac{N_T}{E\,A_S} \tag{8}$$

where:

$\epsilon_T$ = ring compressive strain, in./in. (cm/cm),
$N_T$ = ring load, lb/in. (N/cm),
$E$ = stress relaxation modulus, psi (N/cm$^2$), and
$A_S$ = manhole cross-sectional area, in.$^2$/in. (cm$^2$/cm). (For solid wall risers, $A_S$ equals the wall thickness.)

7.1.1.5 *Ring Bending*—The ring strain calculated by Eq 8 will be combined with the bending strain to determine the design adequacy of a proposed wall section.

7.1.1.6 The radial pressures applied to a manhole varies around the circumference due to variability in the fill material and its placement as demonstrated by the 1.21 factor in Eq 1. This eccentricity introduces bending strain in the riser wall. The bending strain can be found either by using an equation that relates the deflection in the riser to the strain (such as Molin's Equation) or by the following method, which considers the bending moment induced by the eccentricity of the thrust load. The eccentricity factor, *e*, can be calculated from Eq 9. It can be assumed that the ring bending deflections will be low and generally on the order of one or two percent of the manhole diameter.

$$e = C_o\,(D_M/2) \tag{9}$$

where:

$e$ = eccentricity, in. (cm),
$C_o$ = 0.02 ovality correction factor for 2 % deflection, and
$D_M$ = mean diameter of manhole, in. (cm).

7.1.1.7 The resulting bending moment due to the ring thrust acting over the eccentricity can be found from Eq 10.

$$M_E = e\,(N_T)\,(0.5) \tag{10}$$

where:

$M_E$ = bending load, in.-lb/in. (N-cm/cm),
$e$ = eccentricity in. (cm), and
$N_T$ = ring thrust, lb/in.

7.1.1.8 The bending strain, $\epsilon_B$, for a given section is given in Eq 11.

$$\epsilon_B = \frac{M_E}{E\,S_X} \tag{11}$$

where:

$\epsilon_B$ = bending strain, in./in. (cm/cm),
$S_X$ = section modulus, in.$^3$/in. = $I/c$ (cm$^3$/cm),
$I$ = moment of inertia of manhole wall, in.$^4$/in. (cm$^4$/cm),
$c$ = distance from riser centroid to surface, in. (cm), and
$E$ = stress relaxation modulus of HDPE, psi (N/cm$^2$).

NOTE 7—If the stress relaxation modulus for bending is different than the stress relaxation modulus for compression, the respective values should be used in Eq 8 and Eq 11. (Stress relaxation values may be obtained from the manhole manufacturer or HDPE resin supplier.)

7.1.1.9 *Combined Ring Compression and Ring Bending Strain*—The total ring strain occurring in the manhole riser wall is given by Eq 12.

$$\epsilon_C = \epsilon_T + \epsilon_B \tag{12}$$

where:

$\epsilon_C$ = combined ring strain, in./in. (cm/cm),
$\epsilon_T$ = compressive thrust strain, in./in. (cm/cm), and
$\epsilon_B$ = bending strain, in./in. (cm/cm).

7.1.1.10 The wall thickness should be designed so that the combined ring strain in Eq 12 is less than the material's permissible strain limit (capacity). Strain capacity of HDPE can vary depending on the particular resin, its molecular weight, and its molecular weight distribution. Because of the variations in HDPE resins and blends, the strain limit should be established for each particular material. The strain limit may be determined by accelerated laboratory testing. Test data for the end-user should be available from the manufacturer.

7.1.1.11 An alternate design approach is to design for stress rather than strain and use an allowable compressive stress value. This method can be used by converting the strain in Eq 12 to a combined stress value.

NOTE 8—The limiting stress approach is usually applied to pressure pipe where the pipe is subjected to long-term hoop stress that must be kept below the threshold for developing slow crack growth within the design life. For several years, it was customary to design non-pressure rated HDPE pipes using an allowable compressive stress approximately equal to the hydrostatic design stress. However, it has recently been shown that the long-term, compressive design stress is higher than the hydrostatic design stress, primarily due to a difference in failure mechanisms.

7.1.1.12 *Ring Buckling*—If the ring compressive thrust stress exceeds a critical value, the manhole can lose its ability to resist flexural deformation and undergo ring buckling. Moore and Selig have used continuum theory to develop design equations for buckling **(7)**. The continuum theory addresses buckling of cylindrical structures surrounded by soil. The presence of groundwater tends to lower the critical buckling value as fluid pressure is not relieved by small deformations that would promote arching in soil. A solution for hydrostatic pressure effects has not yet been published using the continuum theory. At present the most commonly used solution for groundwater effects is Luscher's equation as given in AWWA C-950 **(8)**.

7.1.1.13 *Manhole Section Above Groundwater Level*—The critical ring thrust at which buckling occurs is given by Eq 13. See Moore et al. **(9)**.

$$N_{CR} = 0.7\, R_H\, (EI)^{1/3}\, (E_S)^{2/3} \tag{13}$$

where:

$N_{CR}$ = critical ring thrust (no groundwater), lb/in. (N/cm),
$R_H$ = geometry factor,
$E$ = stress relaxation modulus, psi (N/cm$^2$),
$I$ = moment of inertia of manhole wall, in.$^4$/in. (cm$^4$/cm), and
$E_S$ = Young's modulus of the soil, psi (N/cm$^2$).

The geometry factor is dependent on the depth of burial and the relative stiffness between the embedment soil and in situ soil. Where the width of the circular zone of fill equals the manhole riser radius, the value of $R_H$ approaches unity as the relative stiffness between the manhole and the soil approaches 0.005. Relative stiffness is defined as:

$$\text{Relative Stiffness} = \frac{2.6\, EI}{E_S r^3} \tag{14}$$

where:

$r$ = radius of manhole riser, in. (cm).

For almost all HDPE manholes installed in a granular or compacted, cohesive-granular embedment, the relative stiffness will be less than 0.005 and $R_H$ equals 1.0. Moore **(9)** also showed that for deep burial in uniform fills, $R_H$ equals 1.0.

7.1.1.14 For design purposes, the ring thrust as given by Eq 7 should not exceed one-half the critical ring thrust, $N_{CR}$.

7.1.1.15 *Manhole Section Below Groundwater Level*—The critical thrust for buckling beneath the groundwater level can be determined using Eq 15. See Ref **(8)**.

$$N_{CRW} = 2.825 \sqrt{\frac{RB'\, E'\, EI}{D_M}} \tag{15}$$

where:

$N_{CRW}$ = critical ring thrust (groundwater), lb/in. (N/cm),
$D_M$ = mean diameter, in. (cm),
$R$ = 1-.33 $H'/H$, buoyancy reduction factor,
$H'$ = height of groundwater above invert, ft (m),
$H$ = height of fill, ft (m),
$E'$ = modulus of soil reaction, psi (N/cm$^2$),
$E$ = stress relaxation modulus, psi (N/cm$^2$), and
$I$ = moment of inertia of manhole wall, in.$^4$/in. (cm$^4$/cm).

and:

$$B' = \frac{1}{1 + 4e^{(-0.065H)}} \quad \left(B' = \frac{1}{1 + 4e^{(-0.213H)}}\right) (SI \text{ units}) \tag{16}$$

7.1.1.16 For design purposes, the ring thrust as given by Eq 7 should not exceed one-half the critical ring thrust, $N_{CRW}$.

7.1.1.17 When radial stiffeners are provided in the manhole wall, the average moment of inertia of the wall can be used in the above equations. But, a check should be made to ensure that the spacing between stiffeners does not permit local buckling.

7.1.2 *Axial Load Performance Limits*—In the above section on earth loading, the axial load due to downdrag was given. In addition to the downdrag, other axial loads include the weight of the manhole and its appurtenances and the weight of any live loads, such as equipment or vehicles. These loads create an axial, compressive strain in the manhole wall. The strain is limited by the compressive strain capacity of the material and by the strain limit at axial buckling. Both limits are calculated and the smallest allowable strain controls design.

7.1.2.1 *Axial Strain*—The maximum axial strain induced by the downdrag shear occurs at the riser's lowest point. Assuming uniform downdrag the strain in a solid wall riser is constant around the perimeter of the riser. For profile walls, the axial strain will vary along the length of the profile and possibly around the perimeter depending on the wall thickness at a given section. The wall thickness at the thinnest point is usually referred to as the "net section" and it equals the manhole wall thickness minus the height of any hollow geometric cores. For solid wall risers, the net wall equals the riser wall thickness.

The maximum axial strain occurs at the net section. The maximum axial, compressive strain, $\epsilon_A$, resulting from the downdrag force acting in the net section of the riser wall is given by Eq 17.

$$\epsilon_A = \frac{P_D + P_l + P_W}{E \pi D_M t_n} \tag{17}$$

where:

$\epsilon_A$ = axial compressive strain, in./in. (cm/cm),
$P_D$ = downdrag force from Eq 4, lb (N),
$P_l$ = live load, lb (N),
$P_W$ = dead load including riser weight, lb (N),
$E$ = stress relaxation modulus, psi (N/cm$^2$),
$D_M$ = mean diameter of manhole, in. (cm), and
$\epsilon_n$ = net wall thickness, in. (cm).

7.1.2.2 For design, the maximum axial strain must be less than the allowable strain for the manhole material.

7.1.2.3 *Axial Buckling*—As the axial strain is increased in a cylindrical tube, supported by soil, the tube is subject to local buckling rather than column buckling. In the lowest (local) buckling modes, the tube will deflect outward slightly and dimple inward. For a buried manhole, the resistance to buckling in this manner is increased by the surrounding soil, which acts to restrain outward deflection. Buckling equations for a cylindrical tube with no soil support are given in the literature. These equations can be used for manhole design but give a conservative value in cases where the surrounding soil is a stable, well-compacted granular material.

7.1.2.4 One such equation is given by Timoshenko and Gere **(10)**. It can be restated in terms of the critical strain as given below:

$$\epsilon_{CR} = \frac{2S_E}{D_M\sqrt{3(1-\mu^2)}} \tag{18}$$

where:

$\epsilon_{CR}$ = critical axial strain, in./in. (cm/cm),
$D_M$ = mean diameter of manhole, in. (cm),
$\mu$ = Poisson's ratio of HDPE, and
$S_E$ = equivalent solid wall thickness, in. (cm).

$$S_E = \sqrt[3]{12I} \tag{19}$$

where:

$I$ = wall cross-section moment of inertia, in.$^4$/in.

7.1.2.5 For the design of buried manholes, this equation can be applied without a safety factor, as the soil support will provide sufficient safety factor and the axial loads on a viscoelastic manhole are believed to be considerably lower than predicted by the method given herein. (Where soil support is minimal, such as in saturated loose or saturated fine grain material, an appropriate safety factor should be applied to Eq 18.)

7.1.2.6 Wall buckling due to axial downdrag usually occurs over a large length of wall. On profile wall risers, the shape of the profile determines whether buckling is initiated by the average wall strain or by the maximum net strain. For profiles with circular cores, the average wall strain usually controls buckling. The average wall strain can be found by substituting the cross-sectional area of the profile wall for the net wall strain value in Eq 17.

7.1.2.7 Methods used for calculating buckling resistance of buried horizontal cylinders subject to axial loads may be applied to the vertical manhole riser. See Chau et al. **(11)** and Chau **(12)**.

7.1.2.8 Practical experience has shown that uneven placement of fill around a manhole and non-uniform settlement of the fill can induce bending in the manhole riser. This bending leads to tensile strains occurring in the axial direction in the manhole. Insufficient information exists for quantifying these strains, however, field experience has indicated that manholes constructed from HDPE with a high resistance to slow crack growth can sustain these strains.

7.1.2.9 *Interaction of Axial and Radial Buckling*—The critical stress at which radial buckling occurs is reduced by axial loading. Normally, this interaction is ignored. This is supported by elastic stability methods given in Timoshenko and Gere **(10)**. However, Chau et al. have published a biaxial buckling equation **(12)**.

7.2 *Manhole Bottom/Floor Design Considerations*—For manholes installed with bases meeting the requirements of 4.2, the downdrag load carried by the manhole riser wall is transferred directly into the base at the contact surface between riser wall and soil without need of a manhole bottom. Where manholes are located beneath the groundwater table and a manhole bottom is provided, the critical load acting on the bottom is groundwater pressure. The bottom is usually a flat circular plate with or without gussetting. In many cases, it also serves as the floor of the manhole. For bottoms located above the groundwater level and where runoff cannot saturate the manhole trench, creating a perched water level, the bottom thickness can be nominal. However, where uplift pressures act on the bottom from water, the bottom must be sized to limit bending stress and deflection. Manhole floors are generally limited to a deflection not greater than two percent for 60 in. (150 cm) and smaller diameter and not greater than one percent for larger diameters. Larger deflections may be tolerable but pumps or other equipment located on the floor can become unstable.

7.2.1 In lieu of finite element analysis, empirical results, or analytical equations, the following equations taken from Sealy and Smith **(13)** may be used. It is usually assumed that yielding occurs around the outer perimeter and that the maximum stresses are at the center of the bottom.

$$\sigma = \frac{3}{4}p\frac{r^2}{t^2} \tag{20}$$

where:

$\sigma$ = maximum stress, psi (N/cm$^2$),
$p$ = groundwater pressure, psi (N/cm$^2$),
$r$ = radius of bottom, in. (cm), and
$t$ = plate thickness, in. (cm).

$$\delta = \frac{3}{16}(1-\mu^2)\frac{pr^4}{Et^3} \tag{21}$$

where:

$\delta$ = maximum deflection, in. (cm),
$\mu$ = Poisson's ratio,
$p$ = groundwater pressure, psi (N/cm$^2$),
$r$ = radius of bottom, in. (cm),
$t$ = plate thickness, in. (cm), and
$E$ = stress relaxation modulus, psi (N/cm$^3$).

7.2.1.1 Stiffening gussets can be added to the manhole bottom to reduce stress and deflection. An analysis should be made to prove that these stiffeners are adequate and that the shear stress in the weld between the stiffeners and the bottom is acceptable.

7.2.1.2 Manhole bottoms that are not flat plates, such as an invert and bench construction, may be considered on the basis of more sophisticated analysis or physical testing. Since these features are normally not embedded in soil, they should be designed for an unsupported buckling resistance capable of handling the design groundwater pressure.

7.3 *Manhole Top/Cone Design Considerations*—Polyethylene flat-plate tops and cones can be designed to carry light live-loads, such as personnel and light equipment. The top design should be proven sufficient by either testing or by design calculations.

7.3.1 For applications subject to vehicular loading, a concrete cap is normally placed over the manhole or the polyethylene manhole top is cast in concrete. Although PE tops can be designed to withstand the weight of H-20 loads, repeated traffic loads can cause significant deflection of the top and the riser. The deflection may not damage the PE, but it may lead to severe cracking of pavement. Before accepting a PE top for installation under traffic loading without a concrete cap or encasement, the designer is advised to seek test data from the manufacturer showing its acceptability for vehicular loading.

7.3.2 When designing a manhole for vehicular loads, consideration should be given to whether or not the live-load force is transmitted into the manhole barrel. Where a concrete cap is set directly onto the manhole riser, the live-load force will be transmitted into the riser and, for design, it should be added directly to $P_D$ in Eq 4. Where the cap rests on the soil so that there is no direct load transfer into the HDPE riser, the amount of live-load force transmitted to the riser will depend on the radial pressure at the top of the manhole. In lieu of a direct determination of this value, an approximate method is to convert the wheel load to an equivalent surcharge load applied over the entire area of the concrete slab. Then multiply this value by $K_A$ to obtain the radial pressure at the top of the manhole ($P_{R1}$ in Eq 3). For manholes more than 10 ft (3.05 m) deep this is usually a negligible value, and therefore the live-load force is ignored.

7.3.3 Ring compression in the manhole barrel resulting from radial pressure due to a vehicular live-load acting on the manhole should be considered. This pressure is significantly reduced by a properly designed concrete manhole cap. (An example of this would be a cap that extends downward below the manhole top a few inches to encompass the very top of the manhole riser.) Where concrete caps are not used, an analysis should be made to determine if the manhole barrel is of sufficient stiffness to resist this radial pressure.

7.4 *Manhole Riser Section Joints*—Riser sections should be joined by thermal fusion or gasket joints. Where riser sections are joined by a gasket joint, the joint should meet the requirements of Specification D 3212.

7.4.1 *Manhole Cone Joint*—Where gasket joints are required to seal the connection between a manhole cone or top, the gasket joint should be demonstrated by testing to provide an adequate seal for the maximum water-head expected for the intended service.

## 8. Keywords

8.1 downdrag; earth loads; manholes; PE pipe; polyethylene; profile pipe

## APPENDIXES

### (Nonmandatory Information)

## X1. PRESUMPTIVE SOIL VALUES FOR DESIGN

X1.1 Presumptive values for the Young's Modulus of Soil used in Eq 13 are given in Table X1.1 and Table X1.2.

TABLE X1.1 Typical Range of Values for Modulus $E_s$[A]

| Clay | ksf | Mpa |
|---|---|---|
| **Clay** | | |
| Very soft | 50 to 250 | 2 to 15 |
| Soft | 100 to 500 | 5 to 25 |
| Medium | 300 to 1000 | 15 to 50 |
| Hard | 1000 to 2000 | 50 to 100 |
| **Sand** | | |
| Silty | 150 to 450 | 7 to 21 |
| Loose | 200 to 500 | 10 to 24 |
| Dense | 1000 to 1700 | 48 to 81 |
| **Sand and Gravel** | | |
| Loose | 1000 to 3000 | 48 to 144 |
| Dense | 2000 to 4000 | 96 to 192 |

[A] Taken from Ref **(13)**, p. 67.

TABLE X1.2 Typical Range of Values for Poisson's Ratio μ[A]

| Soil | μ |
|---|---|
| Clay, saturated | 0.4 to 0.5 |
| Clay, unsaturated | 0.1 to 0.3 |
| Sand (dense) | 0.2 to 0.4 |

[A] Taken from Ref **(13)**, p. 67.

## X2. MANHOLE APPURTENANCES

X2.1 *Manhole Ladders*—Ladders used in HDPE manholes may be made from HDPE or other corrosion-resistant materials. Ladders may be permanently attached to the manhole, if the ladder and its placement within the manhole meet all applicable OSHA standards for ladders and their use and if the method of attachment has been proven sufficient by calculations or testing. Manholes should be entered only by qualified personnel wearing proper safety equipment including proper gas detection equipment, and cable and harness or a similar restraining device to protect from falls.

X2.2 *Manhole Lifting Lugs*—Where lifting lugs or other external devices are provided to ease handling and placement of manholes, the design of such lugs should be verified by calculations or testing. The end-user is advised to thoroughly acquaint himself with all manufacturer's literature on handling of manholes. Most manhole manufacturers require that all lifting lugs be utilized simultaneously when lifting.

X2.3 *Antiflotation Devices*—Where manhole risers extend beneath the groundwater level, considerable uplift force may act on the manhole bottom. This force may be sufficient to overcome the frictional resistance between the manhole and soil and cause the manhole to move upward and off-grade. Several approaches have been used to anchor the manhole against this flotation. The designer should make an analysis as to whether or not anchoring is required. This analysis should include determining the uplift force and comparing it to the frictional resistance of the soil. For this determination, a low estimate of the coefficient of friction between soil and riser is conservative. Where an antiflotation device is employed, the designer should perform calculations to determine not only that the manhole will not float but that the device will not be overstressed. Conservative devices include: anchoring the manhole to a concrete base slab, extending the base of the manhole beyond the manhole riser outer diameter and placing a concrete anchor ring over it, welding a circular ring to the riser and placing a concrete anchor ring over it. For this case, shear stress between the HDPE ring and manhole barrel must be below the allowable. In the second and third case, the concrete anchor ring uses the soil weight for resistance. HDPE rings alone may provide sufficient resistance, however, the designer should check to determine they do not undergo excessive bending and allow small upward movements. HDPE anchor rings or HDPE shelves on which to place concrete anchor rings, must be kept near the bottom of the manhole, otherwise considerable downdrag load is added and may overload the riser.

## X3. SAMPLE CALCULATIONS

X3.1 *Given Information:*

X3.1.1 *Minimum Manhole Dimensions and Geometric Properties*—For this example, consider a manhole shaft wall manufactured from a closed profile wall with a single layer of circular hollow cores (coretubes) centered on the centroid of the shaft wall and having the following dimensions and geometric properties:

| | |
|---|---|
| Manhole inside diameter (in.) | D = 48 in. (122 cm) |
| Moment of inertia (in.$^4$/in.) | $I = 0.367\ in.^4 / in.$ $(6.01\ cm^4 / cm)$ |
| Cross sectional area (in.$^2$/in.) | $A = 0.752\ in.^2 / in.$ $(1.91\ cm^2 / cm)$ |
| Centroid (in.) | $ZC$ = 0.913 in. (2.32 cm) |
| Wall Height (in.) | $h$ = 1.83 in. (4.65 cm) |
| Net wall thickness (in.) | $t_n$ = 0.38 in. (0.97 cm) $t_n$ equals $h$ minus coretube diameter |
| Manhole base plate thickness (in.) | $t_p$ = 2.0 in. (5.08 cm) |

X3.1.2 *Material Properties for Selected HDPE:*

| | |
|---|---|
| Long-term stress relaxation modulus at 73°F (23°C), (psi) | $E$ = 28 250 psi (19 478 N/cm$^2$) |
| Long-term Poisson's Ratio of HDPE | $\mu = 0.48$ |
| Long-term Allowable Compressive Stress at 73°F (23°C) (psi) | $C_s$ = 1000 psi (689 N/cm$^2$) |

NOTE X3.1—The typical value for the allowable compressive stress for materials meeting the requirements of 5.1 and having an HDB of 1600 psi (1100 N/cm$^2$) is 1000 psi (689 N/cm$^2$).

NOTE X3.2—The axial compressive strain is limited to 3.5 % to prevent the long-term stress in the HDPE from exceeding 1000 psi.

$$\epsilon_{cal} = 0.035 \frac{\text{in.}}{\text{in.}}\left(0.035 \frac{\text{cm}}{\text{cm}}\right) \tag{X3.1}$$

| | |
|---|---|
| Long-term allowable ring bending strain at 73°F, (°C) | $\epsilon_{bal}$ = 0.05 in./in.(0.05 cm/cm) |

NOTE X3.3—The typical value for the allowable ring bending strain for materials meeting the requirements of 5.1 is 5 %.

| | |
|---|---|
| Long-term allowable tensile stress at 73°F, (°C), psi (KPa) | $\sigma_{tal}$ = 800 psi (550 N/cm$^2$) |

NOTE X3.4—The long-term allowable tensile stress for materials meeting the requirements of 5.1 and having an HDB of 1600 psi (1100 N/cm$^2$) is 800 psi (550 N/cm$^2$).

X3.1.3 *Soil and Installation Information*:

| | |
|---|---|
| Depth of manhole, ft | $H$ = 18 ft (5.49 m) |
| Depth from surface to groundwater (ft) | $Z$ = 10 ft (3.05 m) |
| Saturated soil weight (lb/ft$^3$) | $S_w = 135\ lbf / ft^3\ (21.21\ kN / m^3)$ |
| Dry soil weight (lb/ft$^3$) | $D_w = 120 \frac{lbf}{ft^3} \left(18.85 \frac{kN}{m^3}\right)$ |
| Angle of internal friction (degrees) | $\theta = 30°$ |
| Modulus of soil reaction (psi) | $E' = 1000\ psi \left(689 \frac{N}{cm^2}\right)$ |
| Manhole design temperature (°F) (Usually 73.4 to 140°F) | T = 73 (23°C) |
| Coefficient of friction for HDPE to soil | $\mu_f = 0.4$ |

| | |
|---|---|
| Young's modulus of soil | $E_S = 7000 \cdot psi \left(4826 \dfrac{N}{cm^2}\right)$<br>(*See* X1 *for typical values.*) |
| Geometry factor formation Moore's eq | $R_H = 1.0$ |

X3.2 *Calculation:*

X3.2.1 *Radial Earth Pressure (see* 6.2.1 *and* 6.3.1*)*:

X3.2.1.1 Paragraph 6.2.1 gives the equation for the radial pressure acting on a manhole in dry soil. This equation is modified in 6.3.2 for manholes subjected to external water pressure.

X3.2.1.2 In the sample calculation, the groundwater is assumed to be 10 ft (3.05 m) below the surface. Therefore, the radial pressure at the manhole invert has two components; pressure due to the embedment soil above the groundwater level and pressure due to the embedment soil below the groundwater level. The radial pressure acting on the manhole is found by taking the sum of Eq 1 (acting from 0 to 10 ft (0 to 3 m)) and Eq 5 (acting from 10 to 20 ft (3 to 5.5 m)).

X3.2.1.3 In order to calculate the radial pressure in Eq 1 and Eq 5, the active earth pressure coefficient must be found:

*Ka − Active Earth Pressure Coefficient* (6.2.1 Eq 2):

$$K_a = \left(\tan\left(45° \quad - \frac{\theta}{2}\right)\right)^2 \qquad \text{(X3.2)}$$

$$K_a = 0.333 \qquad \text{(X3.3)}$$

X3.2.1.4 The radial pressure component due to the soil above the groundwater level is found using Eq 1 (see 6.2.1):

$$H_d = Z \quad H_d = 10 \text{ ft (3.05 m)} \qquad \text{(X3.4)}$$

$$P_{rd} = 1.21\, K_a\, D_w\, H_d \quad P_{rd} = 484 \frac{\text{lbf}}{\text{ft}^2} \text{(23.2 kPa)} \qquad \text{(X3.5)}$$

X3.2.1.5 The radial pressure component due to the combined earth pressure and water pressure beneath the groundwater level is found using Eq 5 (6.3.2):

$$H_{sat} = H - Z \quad \gamma_w = 62.4 \frac{\text{lbf}}{\text{ft}^3} \text{(9.8 kN/m}^3\text{)} \qquad \text{(X3.6)}$$

$$P_{rsat} = \gamma_w H_{sat} + 1.21\, K_a\, (S_w - \gamma_w)\, H_{sat} \qquad \text{(X3.7)}$$

$$P_{rsat} = 733.456 \frac{\text{lbf}}{\text{ft}^2} \text{(35.1 kPa)} \qquad \text{(X3.8)}$$

X3.2.1.6 The radial pressure acting at the invert of the manhole shaft equals:

$$P_r = P_{rd} + P_{rsat} \quad P_r = 1217 \frac{\text{lbf}}{\text{ft}^2} \text{(58.3 kPa)} \qquad \text{(X3.9)}$$

X3.2.2 *Downdrag Load (see 6.2.2):*

X3.2.2.1 The downdrag load is found by summing the average shear stress over the surface area of the manhole. The shear stress is equal to the product of the average radial pressure and the coefficient of friction. See Eq 3 (6.2.2.1).

X3.2.2.2 The radial pressure used in Eq 3 is the pressure due to the dry or saturated (but not buoyant) unit weight of the manhole embedment soil taken over the full depth of the manhole, whether the manhole is below the groundwater table or not, as given in Eq 1:

$$P_{rd} = 1.21\, K_a\, S_w\, H \quad P_{rd} = 980 \frac{\text{lbf}}{\text{ft}^2} \text{(46.9 kPa)} \qquad \text{(X3.10)}$$

X3.2.2.3 The average shear stress is found using Eq 3 (see 6.2.2.1).

$$P_{r1} = 0.0 \frac{\text{lbf}}{\text{ft}^2} \text{(0 kPa)} \quad P_{r2} = P_{rd} \qquad \text{(X3.11)}$$

$$T_a = \mu_f \frac{P_{r1} + P_{r2}}{2} \qquad \text{(X3.12)}$$

(Eq 3, 6.2.2.1)

$$T_a = 0.4 \frac{P_{rd}}{2} \quad T_a = 196.02 \frac{\text{lbf}}{\text{ft}^2} \text{(9.4 kPa)} \qquad \text{(X3.13)}$$

X3.2.2.4 The downdrag load can be found using Eq 4 (see 6.2.2.3):

$$D_{od} = D + 2\,h \quad D_{od} = 4.305 \text{ ft (1.31 m)} \qquad \text{(X3.14)}$$

$$P_D = T_a\, \pi\, D_{od}\, H \quad P_D = 47\,720 \text{ lbf (212.4 kN)} \qquad \text{(X3.15)}$$

X3.2.3 *Manhole Shaft Design: Radial Loads:*

X3.2.3.1 The performance limits under radial loads consist of ring compression, ring bending, and ring buckling.

X3.2.3.2 The ring compressive thrust can be found using Eq 7 (see 7.1.1.1) where $P_r$ is converted to units of psi by dividing the value of $P_r$ in psf by 144 (where $P_r$ is converted to units of N/cm$^2$ by dividing the value of $P_r$ in kPa by 10).

$$R_m = \frac{D + 2\,ZC}{2} \quad P_r = 8.455 \text{ psi} \left(5.83 \frac{\text{N}}{\text{cm}^2}\right) \qquad \text{(X3.16)}$$

$$N_t = P_r\, R_m \quad N_t = 210.628 \frac{\text{lbf}}{\text{in.}} \left(369 \frac{\text{N}}{\text{cm}}\right) \qquad \text{(X3.17)}$$

X3.2.3.3 The ring compressive strain can be found using Eq 8:

$$\epsilon_t = \frac{N_t}{E\,A} \quad \epsilon_t = 0.01 \frac{\text{in.}}{\text{in.}} \left(0.01 \frac{\text{cm}}{\text{cm}}\right) \qquad \text{(X3.18)}$$

X3.2.3.4 The ring compressive strain should be less than the allowable compressive strain.

$$\epsilon_t = 0.01 \frac{\text{in.}}{\text{in.}} \left(0.01 \frac{\text{cm}}{\text{cm}}\right) < \epsilon_{\text{cal}} = 0.035 \frac{\text{in.}}{\text{in.}} \left(0.035 \frac{\text{cm}}{\text{cm}}\right) \qquad \text{(X3.19)}$$

X3.2.3.5 The bending strain can be found from the manhole eccentricity. Some eccentricity is assumed to occur because of installation and handling forces. For manhole shafts, this is typically 2 % of the diameter. However, since the shaft is reinforced against ring deflection by the manhole bottom, the maximum eccentricity will not occur at the point of maximum radial pressure.

X3.2.3.6 The eccentricity is given by Eq 9:

$$C_o = 0.02 \qquad \text{(X3.20)}$$

$$e = C_o\, R_m \quad e = 0.498 \text{ in. (1.27 cm)} \qquad \text{(X3.21)}$$

X3.2.3.7 The resulting bending moment due to ring thrust is given by Eq 10:

$$M_E = e\, N_t\, 0.5 \quad M_E = 52.47 \text{ in.} \frac{\text{lbf}}{\text{in.}} \left(233.7 \frac{\text{N−cm}}{\text{cm}}\right) \qquad \text{(X3.22)}$$

X3.2.3.8 Eq 11 gives the bending strain:

$$S_X = \frac{1}{ZC} \qquad \text{(X3.23)}$$

$$\epsilon_b = \frac{M_E}{E\, S_X} \quad \epsilon_b = 0.005 \frac{\text{in.}}{\text{in.}} \left(0.005 \frac{\text{cm}}{\text{cm}}\right) \qquad \text{(X3.24)}$$

X3.2.3.9 The combined bending and compressive strain can be found from Eq 12:

$$\epsilon_c = \epsilon_t + \epsilon_b \quad \epsilon_c$$
$$= 0.015 \frac{\text{in.}}{\text{in.}} (0.015 \text{ cm/cm}) < \epsilon_{bal}$$

$$= 0.05 \frac{\text{in.}}{\text{in.}} \left(0.05 \frac{\text{cm}}{\text{cm}}\right) \tag{X3.25}$$

Both the ring compressive stress criterion given in X3.2.3.4 above and the allowable combined strain criterion must be met.

X3.2.3.10 Two equations are given in the standard for checking buckling. Eq 13 is for use in dry ground applications or above the groundwater level. Eq 15 is for shafts located below the groundwater level. Both the "dry" and "wet" portions of the shaft in this example are checked.

X3.2.3.11 Eq 13 is used for checking radial buckling of manholes above the groundwater level and would apply to the upper 10 ft (3 m) of this manhole:

$$N_{cr} = 0.7\, R_H\, (EI)^{1/3}\, E_s^{\,2/3} \quad N_{cr} = 5585 \frac{\text{lbf}}{\text{in.}} \left(9779 \frac{\text{N}}{\text{cm}}\right) \tag{X3.26}$$

Applied radial load on upper 10 ft (3 m) of manhole shaft equals:

$$H_d = 10 \text{ ft } (3 \text{ m}) \tag{X3.27}$$

$$P_{rd'} = K_a\, D_w\, H_d\, 1.21 \quad P_{rd'} = 484 \frac{\text{lbf}}{\text{ft}^2} (23.2 \text{ kPa}) \tag{X3.28}$$

$$N_{td} = P_{rd'}\, R_m \quad N_{td} = 83.74 \frac{\text{lbf}}{\text{in.}} = 146.8 \frac{\text{N}}{\text{cm}} \tag{X3.29}$$

$$SF = \frac{N_{cr}}{N_{td}} \quad SF = 66.7 \quad > 2 \tag{X3.30}$$

X3.2.3.12 Radial buckling of the portion of the manhole shaft submerged beneath the groundwater table is given by Eq 15.

$$R_w = 1 - 0.33 \frac{H - Z}{H} \quad R_w = 0.853 \tag{X3.31}$$

$$e = 2.71828 \tag{X3.32}$$

where:

$e$ = natural log base number

$$B' = \left(\frac{1}{1 + 4\, e^{-0.065 \cdot H \cdot \frac{1}{\text{ft}}}}\right) \quad \left(B' = \frac{1}{1 + 4 \cdot e^{-0.213 \cdot H \cdot \frac{1}{\text{m}}}}\right)(SI) \tag{X3.33}$$

$$D_m = D + 2\, ZC \tag{X3.34}$$

$$N_{crw} = 2.825 \left[\frac{R_w\, B'\, E'\, E\, (I)}{D_m}\right]^{1/2} N_{crw} = 795 \frac{\text{lbf}}{\text{in.}} \left(139 \frac{\text{N}}{\text{cm}}\right) \tag{X3.35}$$

Determine the *SF* using $N_t$ from X3.2.3.2:

$$SF = \frac{N_{crw}}{N_t} \quad SF = 3.77 \quad > 2 \tag{X3.36}$$

X3.2.4 *Manhole Shaft Design: Axial Loads:*

X3.2.4.1 The axial strain in the net wall section can be found using Eq 17:

$$P_D = 47\,720 \text{ lbf } (212\,400\, N) \tag{X3.37}$$

$$P_l = 0 \text{ lbf } (0\, N) \tag{X3.38}$$

where:

$P_l$ = live load

$$P_w = 900 \text{ lbf } (4\,000\, N) \tag{X3.39}$$

where:

$P_w$ = weight of manhole shaft

$$\epsilon_a = \frac{P_D + P_l + P_w}{E\, \pi\, D_m\, t_n} \quad \epsilon_a = 0.029 \frac{\text{in.}}{\text{in.}} \left(0.029 \frac{\text{cm}}{\text{cm}}\right) \tag{X3.40}$$

X3.2.4.2 The net wall axial strain should be less than the allowable axial compressive strain based on the long-term strength rating of the material. See X3.1:

$$\epsilon_a = 0.029 \frac{\text{in.}}{\text{in.}} \left(0.029 \frac{\text{cm}}{\text{cm}}\right) < \epsilon_{cal} = 0.035 \frac{\text{in.}}{\text{in.}} \left(0.035 \frac{\text{cm}}{\text{cm}}\right) \tag{X3.41}$$

X3.2.4.3 The critical strain at axial buckling of the shaft can be determined from Eq 18:

$$S_E = (12\, I)^{1/3} \quad S_E = 1.639 \text{ in. } (4.16 \text{ cm}) \tag{X3.42}$$

$$\epsilon_{cr} = \frac{2\, S_E}{D_m\, [3\,(1 - \mu^2)]^{1/2}} \quad \epsilon_{cr} = 0.043 \frac{\text{in.}}{\text{in.}} \left(0.043 \frac{\text{cm}}{\text{cm}}\right) \tag{X3.43}$$

X3.2.4.4 For the closed profile shapes in Specification F 894, the average wall strain controls axial buckling, rather than the net wall strain as calculated in X3.2.4.2. The average axial compressive strain can be found from Eq 17 by substituting the cross-sectional area for the net wall thickness:

$$\epsilon_a = \frac{P_D + P_l + P_w}{E\, \pi\, D_m\, A} \quad \epsilon_a = 0.015 \frac{\text{in.}}{\text{in.}} \left(0.015 \frac{\text{cm}}{\text{cm}}\right) \tag{X3.44}$$

$$SF = \frac{\epsilon_{cr}}{\epsilon_a} \quad SF = 2.87 \tag{X3.45}$$

NOTE X3.5—A *SF* of 1 is considered sufficient since the support provided by the soil in restraining axial buckling is not included in Eq 18.

X3.2.5 *Manhole Base/Bottom Design*:

X3.2.5.1 The primary load acting on the manhole bottom is due to groundwater.

$$p_{gw} = 62.4 \frac{\text{lbf}}{\text{ft}^3} H_{sat} \quad p_{gw} = 3.47 \text{ psi} \tag{X3.46}$$

$$\left(p_{gw} = W\, H_{sat} \frac{100 \text{ cm}}{\text{m}} \quad p_{gw} = 2.39 \frac{\text{N}}{\text{cm}^2}\right) \tag{X3.47}$$

X3.2.5.2 Where the manhole base is constructed from a flat plate with thickness $t_p$ and without gussets, the maximum base stress can be determined using Eq 20:

$$\sigma_{bp} = \frac{3}{4} p_{gw} \frac{\left(\frac{D}{2}\right)^2}{t_p^{\,2}} \quad \sigma_{bp} = 374 \text{ psi} \left(258 \frac{\text{N}}{\text{cm}^2}\right) \tag{X3.48}$$

X3.2.5.3 The maximum stress in the base should be less than the allowable stress for the base plate material.

$$\sigma_{bp} = 374 \text{ psi} \left(258 \frac{\text{N}}{\text{cm}^2}\right) < \sigma_{tal} = 800 \text{ psi} \left(550 \frac{\text{N}}{\text{cm}^2}\right) \tag{X3.49}$$

X3.2.5.4 The upward deflection that occurs in the base plate (manhole floor) should be limited to 2 % of the manhole diameter.

$$\delta_{bp} = \frac{3}{16}\left(1 - \mu^2\right)\frac{p_{gw}\left(\frac{D}{2}\right)^4}{E\, t_p^{\,3}} \quad \delta_{bp} = 0.734 \text{ in. } (1.87 \text{ cm}) \tag{X3.50}$$

$$\Delta\,\% = \frac{\delta_{bp}}{D}100 \quad \Delta\,\% = 1.53 < 2\,\% \tag{X3.51}$$

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