Designation: C1924 – 23

Standard Practice for Design of Buried Precast Concrete Low-Head Pressure Pipe[1]

This standard is issued under the fixed designation C1924; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers the design of buried precast concrete low head pressure pipe having a circular shape and manufactured in accordance with Specification C361/C361M subject to internal pressure not exceeding a pressure head of 125 ft (54 psi), or as otherwise limited herein.

1.2 When buried, concrete pipe is part of a composite system comprised of the pipe and the surrounding soil envelope. Both the pipe and soil envelope contribute to the strength and structural behavior of the system.

1.3 This practice presents the method for evaluating the effects of external loads combined with internal pressure on buried precast concrete low-head pressure pipe manufactured per Specification C361/C361M. This method includes an analysis that accounts for the interaction between the pipe and soil envelope in determining external loads, earth pressure distributions, and the moments, thrusts, and shears for the pipe. It also includes a detailed procedure for designing reinforcement for these installations.

1.4 Construction requirements for precast concrete low-head pressure pipe are in accordance with Specification C361/C361M.

1.5 This practice may be used as a reference by the owner and the owner's engineer in preparing project specifications for low head pressure pipe.

1.6 The design procedures given in this standard are intended for use by engineers who are familiar with the installation and pipe characteristics that affect the structural behavior of buried concrete pipe installations and the significance of the installation requirements.

1.7 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.8 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

A1064/A1064M Specification for Carbon-Steel Wire and Welded Wire Reinforcement, Plain and Deformed, for Concrete

C361/C361M Specification for Reinforced Concrete Low-Head Pressure Pipe

C443 Specification for Joints for Concrete Pipe and Manholes, Using Rubber Gaskets

C655 Specification for Reinforced Concrete D-Load Culvert, Storm Drain, and Sewer Pipe

C822 Terminology Relating to Concrete Pipe and Related Products

D2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)

D2488 Practice for Description and Identification of Soils (Visual-Manual Procedures)

2.2 *ASCE Standards:*[3]

ASCE 15 Standard Practice for Direct Design of Buried Precast Concrete Pipe Using Standard Installations (SIDD)

2.3 *AASHTO Documents:*[4]

LRFD Bridge Design Specifications

2.4 *AREMA Documents:*[5]

Railroad Engineering Manual

[1] This test method is under the jurisdiction of ASTM Committee C13 on Concrete Pipe and is the direct responsibility of Subcommittee C13.04 on Low Head Pressure 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] Available from American Society of Civil Engineers (ASCE), 1801 Alexander Bell Dr., Reston, VA 20191, http://www.asce.org.

[4] Available from American Association of State Highway and Transportation Officials (AASHTO), 444 N. Capitol St., NW, Suite 249, Washington, DC 20001, http://www.transportation.org.

[5] Available from American Railway Engineering and Maintenance-of-Way Association (AREMA), 4501 Forbes Blvd., Suite 130, Lanham, MD 20706, https://www.arema.org.

2.5 *AWWA Documents:*[6]
Manual M9 Design of Reinforced Concrete Pressure Pipe

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms relating to concrete pipe, see Terminology C822.

3.1.2 For terminology related to soil classifications, see Practices D2487 and D2488.

3.1.3 For terminology and definition of terms relating to structural design, see AASHTO LRFD Bridge Design Specification.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *installation requirements, n*—(See Fig. 1.)definitions and limits are shown in Fig. 1.

3.2.2 *internal pressure, n*—The pressure at the inside springline of a concrete pipe.

3.2.2.1 *Discussion*—The designated (design) internal hydrostatic pressure includes operating pressure and transient pressure. Transient pressure includes surge, water hammer and any other dynamic pressure specified by the owner. The designated internal hydrostatic pressure is measured from the springline of the pipe as is customary in pressure pipe terminology, however, precast concrete low head pressure pipe is designed by considering the weight of fluid up to the crown of the pipe and then the pressure above the crown.

3.2.3 *prism load, n*—weight of column of earth over the outside diameter of pipe.

3.2.4 *radial tension strength, n*—the limiting average tensile strength of the concrete in the plane of the inner reinforcement and concrete at the crown and invert regions.

3.2.5 *radial tension stress, n*—(See Fig. 2.) radial tension stress is caused by tensile stress in the inner cage.

3.2.5.1 *Discussion*—The inner reinforcing tends to straighten from an arc to a chord in the crown or invert of the pipe. Only tensile force produced by bending from external load produces radial tension. The tensile force in the reinforcement produced by internal pressure does not produce radial tension.

3.2.6 *shear force, n*—The diagonal tension component of the internal stress resultant produced by external load.

3.2.7 *shear strength (diagonal tension strength), n*—the limiting tensile strength of the concrete resulting from the diagonal component of the shear force.

[6] Available from American Water Works Association (AWWA), 6666 W. Quincy Ave., Denver, CO 80235, http://www.awwa.org.

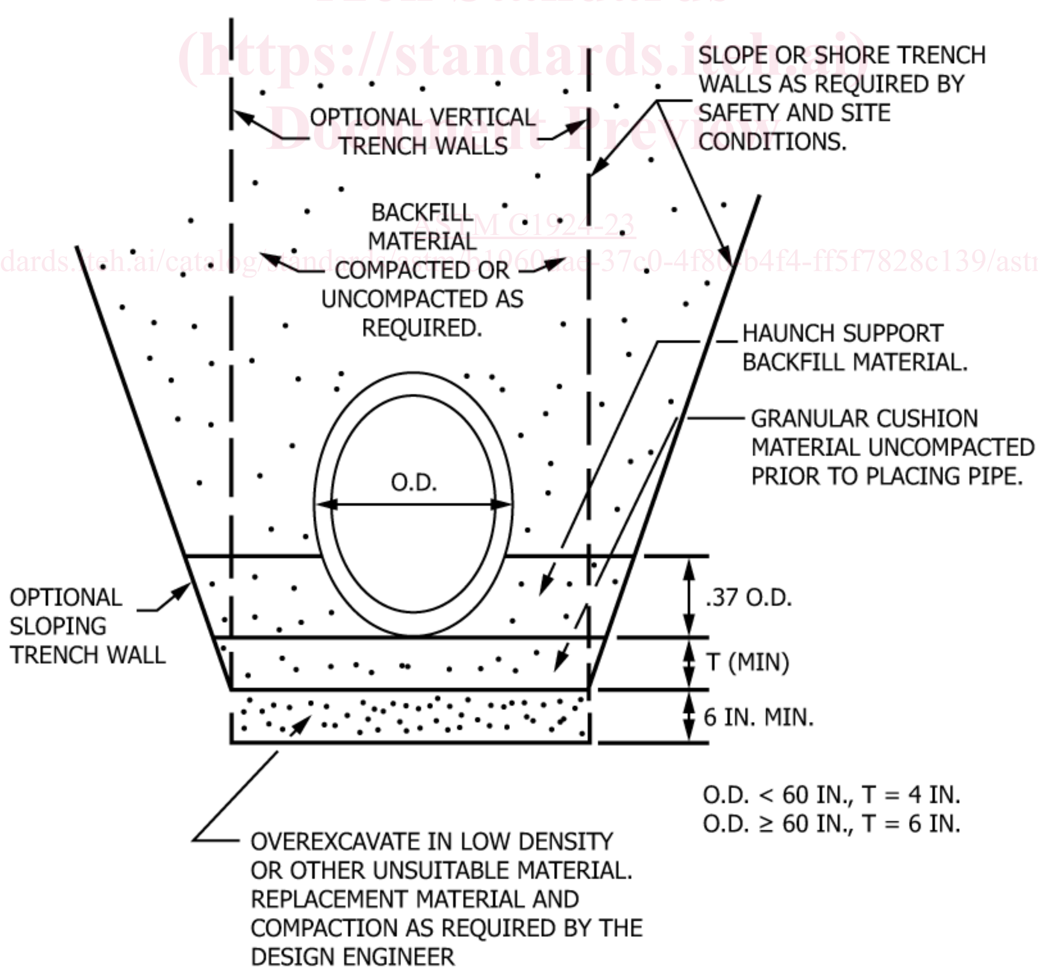

FIG. 1 Installation Definitions

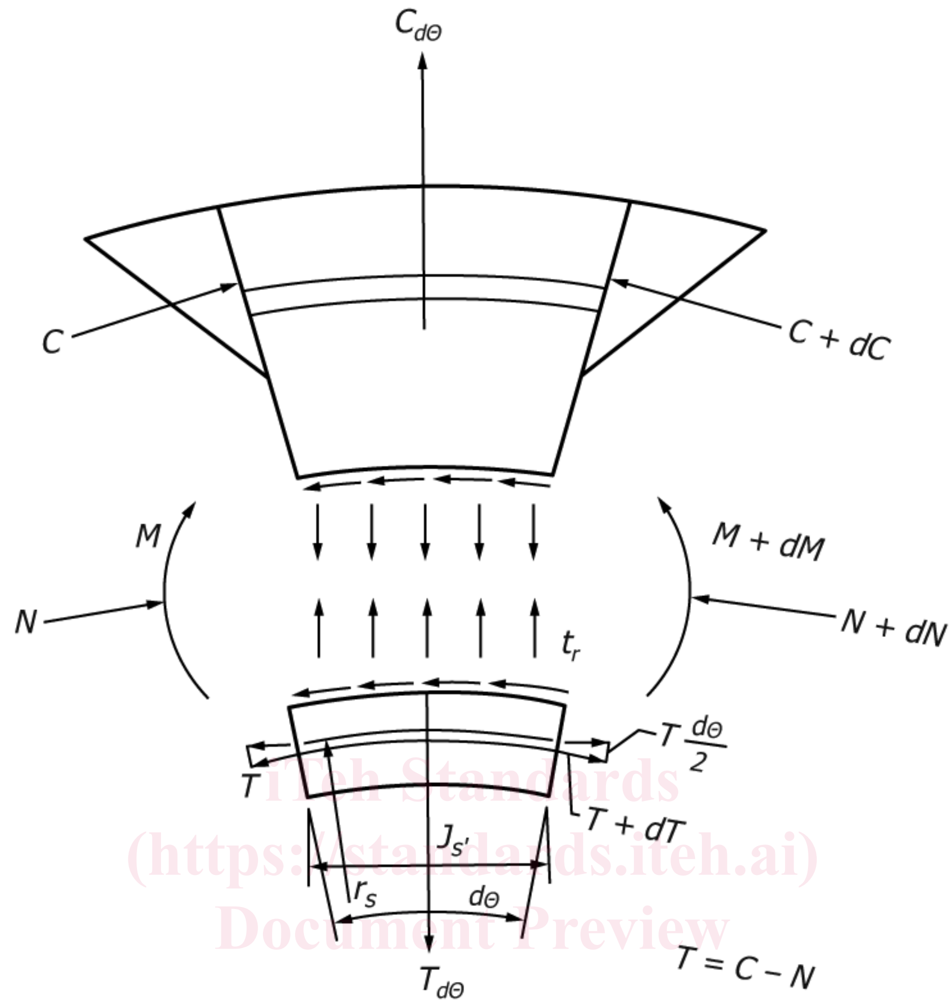

FIG. 2 Radial Tension in Curved Flexural Member at Cracked Section

4. Notations

4.1 The notations used in this practice have the following significance:

α = depth of compressive rectangular stress block produced by combined factored bending and thrust, in.

A_s = area of tension reinforcement provided in length b, in.^{2}/ft

A_{sd} = area of circumferential bell reinforcement required for differential settlement across the joint, in.^{2}/ft

A_{se} = area of circumferential bell reinforcement required for earth load across the joint, in.^{2}/ft

A_{smax} = maximum or limiting value of A_s that can be developed by radial tension strength or flexural compression strength, in.^{2}/ft

A_{si} = area of inner cage reinforcement required in length b, in.^{2}/ft

A_{sreq} = area of circumferential bell reinforcement required from internal pressure and gasket compression across the joint, in.^{2}/ft

A_{vr} = area of stirrup reinforcement required to resist radial tension forces, in.^{2}/ft in each line of stirrups at circumferential spacing s_v, in.

A_{vs} = area of stirrup reinforcement required to resist shear, in.^{2}/ft in each line of stirrups at circumferential spacing s_v

b = unit length of pipe and for design purposes width of section that resists stress, in. (taken as 12 in.)

B_1 = crack control coefficient for effect of spacing and number of layers of reinforcement

BF = total force at the bell of the pipe

BF_1 = force at the bell of the pipe produced from the gasket

BF_2 = force at the bell of the pipe produced from internal pressure

C_m = non-dimensional coefficient for determining the stress resultants for moment

C_n = non-dimensional coefficient for determining the stress resultants for thrust

C_v = non-dimensional coefficient for determining the stress resultants for shear

C_1 = crack control coefficient for various types of reinforcement

d = distance from compression face to centroid of tension reinforcement, in.

D_{ib} = inside diameter of bell, in.

D_{ob} = outside diameter of bell, in.
D_i = inside diameter of pipe, in.
D_m = mean diameter of pipe, in.
D_o = outside diameter of pipe, in.
d_1 = bell thickness, in.
d_2 = effective section depth, in.
e = thrust eccentricity
E_s = modulus of elasticity of steel, psi
f_c = design compressive strength of concrete, lb/in.^{2}
f_{ct} = service load limit of concrete tensile stress caused by internal pressure only, psi
f_v = maximum developable strength of stirrup material, lb/in.^{2}
f_y = design yield strength of reinforcement, lb/in.^{2}
F_c = curvature factor that accounts for the small additional shear associated with the effects of curvature on the pipe wall thrust
F_{cr} = the crack control factor
F_d = size factor that accounts for the increased shear stress capacity exhibited by small diameter pipe with thin walls
$F_{\varepsilon x}$ = strain factor to account for the reduction in aggregate interlock from higher tensile strains
F_{rt} = factor for pipe size effect on radial tension strength
F_{rp} = process and material factor for radial tension strength = 1.00, unless a higher value substantiated by test data obtained in accordance with Specification C655 is approved by the engineer
f_{sd} = service load reinforcing steel tensile stress caused by internal pressure only, on cracked section, psi
F_{vp} = process and material factor for shear strength
h = pipe wall thickness, in.
i = coefficient for effect of axial force at service limits state
I = moment of inertia, in.^{4}
j = coefficient for moment arm at service limit state
H = design height of earth above top of pipe, ft
H_w = hydrostatic head, ft
l_θ = total additional arc length beyond calculated arc lengths requiring stirrups, in.
L_b = depth (inside longitudinal dimension) of bell, in.
M_E = moment resulting from the earth load above the top of the pipe, in.lb/ft
M_P = moment resulting from the weight of the pipe, in.-lb/ft
M_s = service load bending moment, in.-lb/ft (always positive)
M_u = factored moment from gravity loads acting on length b, in.-lb/ft
M_{uv} = factored moment caused by all loads section of maximum shear, based on load factor for shear, in.-lb/ft
M_{ure} = factored moment caused by external loads and weight of fluid at section of maximum moment, based on load factor for radial tension or for concrete compression, in.-lb/ft
n = number of layers of tension reinforcement, not to exceed 2 when used in design
N_P = thrust resulting from the weight of the pipe, lb/ft
N_s = service load axial thrust, lb/ft (+ when compressive, – when tensile)
N_u = factored thrust from gravity loads acting on length b, in.-lb/ft
N_{up} = factored thrust force due to internal pressure, (lb/ft)
N_{ure} = factored compressive thrust at section of maximum moment produced by external load (+ when compressive, – when tensile), based on load factor for radial tension or compressive thrust, lb/ft
N_{uv} = factored compressive thrust at section of maximum shear produced by all loads except internal pressure (+ when compressive, – when tensile), based on load factor for compressive thrust, lb/ft
r = radius to centerline of pipe wall, in.
r_s = radius of the inside reinforcement, in.
s = spacing of the circumferential reinforcement, in.
s_v = circumferential spacing of stirrups, in.
t_b = clear concrete cover over reinforcement, in.
V_c = shear strength provided by concrete without stirrups in length b, lb/ft
V_P = shear resulting from weight of the pipe, lb/in.
V_{uv} = factored shear force at section of maximum shear produced by all loads, lb/ft
W_E = total weight of earth acting on length b of pipe, lb/ft
W_P = weight of pipe for length b, lb/ft
W_f = weight of fluid that fills length b of pipe, lb/ft
y = distance to the neutral axis, in.
α = total bedding angle measured from top of pipe, rad
α' = bedding angle, rad
β = angle to any point on pipe measured from top of pipe, rad
β_1 = coefficient for determining compression stress block height, α
θ = orientation angle, degrees
Θ = bell stress, psi
θ_v = approximate inclination of diagonal tension crack, degrees
ε_{xu} = strain in reinforcement produced by factored moments, thrusts and shears at section of maximum shear, in./in.
ρ_b = reinforcement ratio producing balanced strain conditions
φ = live load angle, rad
φ_f = strength reduction factor for flexure
φ_v = strength reduction factor for shear
φ_r = strength reduction factor for radial tension
φ_{cr} = strength reduction factor for crack control
ω = effective width factor

5. Summary of Practice

5.1 This standard accounts for the interaction between the pipe and soil envelope in determining external loads and distribution of earth pressure on a buried pipe using a radial pressure distribution. The external loads and earth pressure distributions are used to calculate moments, thrusts, and shears in the pipe wall, and together with the pipe weight, water weight, and internal pressure to calculate required pipe reinforcement for the installations.

5.2 Load and earth pressure effects are determined from the radial pressure distribution.

5.3 The structural design of concrete low-head pressure pipe is based on a limits state design procedure that accounts for strength and serviceability criteria, specific procedures for calculating design limits based on shear and radial tension strengths without stirrups, and requirements for stirrup reinforcement. The design procedures are based on current reinforced concrete strength and serviceability design concepts. The design criteria include: structural aspects, such as flexure, thrust, shear and radial tension strengths; handling and installation; and control of reinforcing and concrete tensile strains. The reinforcement and concrete tensile stress (and strain) limits used in this practice are consistent with those used in previous practice based on Specification C361/C361M.

5.4 Concrete tensile stresses, based on an uncracked wall, and reinforcement stresses, based on a cracked pipe assumption, produced by internal pressure acting alone are limited as prescribed in Specification C361/C361M to control strain to preclude excessive cracking and leakage and also to maintain shear resistance.

5.5 The design of a concrete low-head pressure pipe for a particular installation is based on the assumption that the specified design bedding and fill requirements will be achieved during construction of the installation.

5.6 For a structural design equivalent to those found in the tables in Specification C361/C361M, the following bedding assumptions are assumed for design:

Load Condition	Bedding Angle
Earth	90°
Water	90°
Live	90°
Dead	45°

6. General

6.1 Design procedures and criteria shall conform to applicable sections of this practice.

6.2 *Design Submittals:*

6.2.1 The intent of this practice is that the pipe be designed and detailed by the manufacturer in accordance with criteria furnished by the owner and as provided in this standard. Shop drawings and design calculations are to be submitted to the owner for review and approval prior to manufacture.

6.2.2 An alternative to 6.2.1 is that the owner provides the design to the pipe manufacturer for preparation of shop drawings for submittal to the owner for approval.

6.2.3 If the owner prepares a design, the manufacturer may submit an alternate design to the owner for consideration for approval.

7. Design Requirements

7.1 *General Requirements*—The owner/owner's engineer shall establish the following design criteria:

7.1.1 Intended use of pipeline

7.1.2 Pipe inside diameter, D_i

7.1.3 Design internal pressure head, H_w

7.1.4 Pipeline plan and profile drawings with installation cross sections as required.

7.1.5 Design earth cover height above the top of the pipe, H.

7.1.6 In situ soil data sufficient to determine conditions for design (including in situ soil classification and standard penetration test result or unconfined compression strength) and overfill weight, lb/ft^3.

7.1.7 Available bedding and backfill materials.

NOTE 1—Owner may specify backfill with imported materials or in situ materials classified in terms of Practice D2487.

7.1.8 Manufacturing specification: Specification C361/C361M.

7.1.9 Performance requirements for pipe joints.

7.1.10 Design live and surcharge loadings, if any.

7.1.11 Design intermittent internal hydrostatic pressures (transient pressure), if required.

7.1.12 Crack width control criteria.

7.1.13 Cement type, if different than Specification C361/C361M.

7.2 *Structural Design Criteria:*

7.2.1 *Combined Loads*—The pipe shall be designed to resist the flexural and axial stresses from each of the following conditions:

Condition 1	Internal pressure only
Condition 2	External loads (Dead: earth, pipe, and gravity water—Live load) with no internal pressure
Condition 3	A combination of external and internal load acting concurrently

7.2.2 *Load Factors:*

7.2.2.1 *Earth, Pipe Weight, and Water Weight:*

Dead and Earth Load	1.6
Compressive Thrust	1.0
Tensile Thrust/Internal Pressure	1.5
Design for Shear and Radial Tension	1.3

7.2.2.2 *Live Load:*

Moment, Shear and Radial Tension Load Factors	1.75
Compressive Thrust Load Factor	1.3

7.2.3 *Strength Reduction:*

Factors Flexure (φ_f)	0.95
Radial Tension (φ_v)	0.9
Diagonal Tension (φ_r)	0.9
Crack Control (φ_{cr})	0.9

7.3 *Design Criteria by Pipe Manufacturer*—The pipe manufacturer shall submit the following manufacturing design data to the owner for approval.

7.3.1 Pipe Wall Thickness

7.3.2 Concrete Strength

7.3.3 *Reinforcement:*

reinforcement type and specification,
design yield strength,
ultimate strength,
placement and design concrete cover,
cross-sectional areas and diameters,
spacing,
description of longitudinal members, and

if stirrups used, developable stirrup design stress, stirrup shape, placement, and anchorage details.

7.3.3.1 The design yield strength and ultimate (tensile) strength of the tension reinforcement used for design shall be as specified in 8.2.1.

7.3.3.2 The minimum design concrete cover over the reinforcement shall be in accordance with Specification C361/C361M, subsection 7.4.

7.3.4 Pipe Laying Length and Joint Information

8. Materials

8.1 *Concrete:*

8.1.1 Concrete shall conform to the requirements of the manufacturing specification (Specification C361/C361M).

8.2 *Reinforcement:*

8.2.1 Reinforcement shall consist of cold-drawn steel wire, cold-drawn steel welded wire reinforcement, cold-drawn deformed steel wire, or cold-drawn deformed steel welded wire reinforcement conforming to Specification A1064/A1064M.

8.3 *Rubber Gaskets:*

8.3.1 Rubber Gaskets shall conform to the material requirements of Specification C361/C361M.

9. Field Installation Procedures

9.1 Field installation requirements shall follow the requirements of Specification C361/C361M.

10. Loads

10.1 *Dead Loads:*

10.1.1 The dead load of the pipe weight, W_p, shall be considered in the design and shall be based on a reinforced concrete unit weight of 150 lb/ft^3, unless otherwise specified.

10.1.2 The earth load is based on a one-foot length of the prism of earth directly over the outside diameter of the pipe. The effective unit weight of earth in pounds per cubic foot is:

$$w_e = 120 + 24\left(\frac{H}{D_0}\right) \leq 168\text{lb/ft}^3 \quad (1)$$

The earth load on the pipe is:

$$W_E = w_e H(D_o), \text{lb/lin. ft} \quad (2)$$

10.1.3 *Minimum Fill*—For unpaved and flexible pavement areas, the minimum fill, including flexible pavement thickness, over the top outside of the pipe shall be 1 ft, or ⅛ of the outside diameter, whichever is greater. Under rigid pavements, the distance between the top of the pipe and the bottom of the pavement slab shall be a minimum of 9 in. (AASHTO table 12.6.6.3-1) of compacted granular fill.

10.1.4 The dead load of fluid in the pipe, W_f, shall be based on a unit weight of 62.4 lb/ft^3, unless otherwise specified.

10.2 *Live Load:*

10.2.1 Truck loads shall be calculated for the AASHTO HL-93 truck load and distributed in accordance with the AASHTO LRFD Bridge Design Specifications. The lane load portion of HL-93 need not be applied.

10.2.2 Railroad live loads shall be calculated for the specified AREMA Cooper E-series loading and distributed in accordance with the AREMA Manual for Railway Engineering.

10.2.3 Aircraft or other live loads shall be as specified by the owner and distributed in accordance with accepted engineering procedures.

NOTE 2—Live loads are not accounted for in Specification C361/C361M.

10.3 *Internal Hydrostatic Pressure:*

10.3.1 Internal operating and transient hydrostatic design pressure shall be as specified by the owner.

10.3.2 Analysis shall include the weight of the water in the pipe.

10.3.3 The maximum total internal hydrostatic pressure shall not exceed a head of 125 ft.

11. Earth Pressure Distribution

11.1 *Dead Load Earth Pressures*—Dead load and earth pressures around the pipe shall utilize a radial pressure distribution based on theory by Olander[7]. The coefficient for the dead load pressures (earth, pipe weight, and fluid weight) are given in Table 1 and Table 2 for different locations around the perimeter of the pipe.

11.1.1 *Pipe Weight*—For pipe weight, a radial pressure distribution at the pipe support shall be assumed to be sinusoidal, with the peak at the center and zero at the edges. The bedding angle for the pipe weight load is assumed to be 45°.

11.1.2 *Earth Weight*—For earth weight, a radial pressure distribution at the pipe shall be assumed to be supported at the bottom over an arc length subtended by a bedding angle. For an installation meeting the description of Specification C361/C361M, Appendix X1, a 90° bedding may be assumed.

11.1.3 *Fluid Weight*—For fluid weight, a radial pressure distribution at the pipe shall be assumed to be supported at the bottom over an arc length subtended by an angle of 90° degrees.

11.2 *Live Load Earth Pressure*—For live load a uniformly distributed surcharge of any width and a cosine-shaped radial bedding reaction pressure are assumed, as shown in Fig. 3. The recommended coefficients are presented in Table 3. When $\beta = 90°$ use a radial pressure distribution as earth load in Table 2.

[7] Olander, H.C., Stress Analysis of Concrete Pipe, Engineering Monograph No. 6, U.S. Bureau of Reclamation, October 1950

TABLE 1 Radial Stress Distribution coefficient for Self-Weight Load (Wayne W. Smith, Stresses in Rigid Pipe, Transportation Engineering Journal of ASCE)

Bedding angle, deg	Deg. from crown	Self-Weight Load Moment	Self-Weight Load Thrust	Self-Weight Load Shear
45	0	-0.08	-0.07	0.00
	5	-0.08	-0.07	0.02
	10	-0.07	-0.07	0.04
	15	-0.07	-0.06	0.06
	20	-0.06	-0.05	0.08
	25	-0.06	-0.04	0.09
	30	-0.05	-0.02	0.11
	35	-0.04	-0.01	0.12
	40	-0.03	0.01	0.13
	45	-0.01	0.04	0.14
	50	0.00	0.06	0.15
	55	0.01	0.08	0.15
	60	0.02	0.11	0.15
	65	0.04	0.13	0.14
	70	0.05	0.16	0.14
	75	0.06	0.18	0.13
	80	0.07	0.21	0.11
	85	0.08	0.23	0.10
	90	0.09	0.25	0.07
	95	0.09	0.27	0.05
	100	0.10	0.29	0.03
	105	0.10	0.30	0.00
	106.67	0.10	0.31	-0.01
	110	0.10	0.31	-0.03
	115	0.09	0.32	-0.07
	120	0.09	0.33	-0.10
	125	0.07	0.33	-0.14
	130	0.06	0.32	-0.17
	135	0.04	0.32	-0.21
	140	0.02	0.31	-0.25
	145	0.00	0.29	-0.29
	150	-0.03	0.27	-0.32
	155	-0.06	0.25	-0.36
	160	-0.09	0.22	-0.38
	165	-0.12	0.19	-0.36
	170	-0.15	0.17	-0.27
	175	-0.17	0.15	-0.15
	180	-0.17	0.15	0.00

TABLE 2 Radial Stress Distribution Coefficient for Earth and Fluid Loads (Wayne W. Smith, Stresses in Rigid Pipe, Transportation Engineering Journal of ASCE)

		Fluid Load			Earth Load		
Bedding angle, deg	Deg. from crown	Moment	Thrust	Shear	Moment	Thrust	Shear
90	0	-0.07	-0.22	0.00	-0.07	0.38	0.00
	5	-0.07	-0.22	0.02	-0.07	0.38	0.02
	10	-0.07	-0.22	0.04	-0.07	0.38	0.04
	15	-0.06	-0.21	0.06	-0.06	0.39	0.05
	20	-0.06	-0.21	0.07	-0.06	0.39	0.07
	25	-0.05	-0.20	0.09	-0.05	0.40	0.08
	30	-0.04	-0.19	0.10	-0.04	0.41	0.10
	35	-0.03	-0.18	0.11	-0.03	0.42	0.11
	40	-0.02	-0.17	0.12	-0.02	0.43	0.12
	45	-0.01	-0.16	0.13	-0.01	0.44	0.13
	50	0.00	-0.15	0.14	0.00	0.45	0.13
	55	0.01	-0.14	0.14	0.01	0.46	0.13
	60	0.02	-0.12	0.14	0.02	0.47	0.13
	65	0.04	-0.11	0.13	0.03	0.48	0.13
	70	0.05	-0.10	0.12	0.05	0.50	0.12
	75	0.06	-0.09	0.11	0.06	0.51	0.11
	80	0.07	-0.08	0.10	0.07	0.52	0.10
	85	0.07	-0.07	0.08	0.07	0.52	0.09
	90	0.08	-0.07	0.06	0.08	0.53	0.07
	95	0.09	-0.06	0.04	0.09	0.54	0.04
	100	0.09	-0.06	0.01	0.09	0.54	0.02
	103.53	0.09	-0.06	-0.01	0.09	0.54	0.00
	105	0.09	-0.06	-0.02	0.09	0.54	-0.01
	110	0.08	-0.06	-0.05	0.09	0.54	-0.04
	115	0.08	-0.07	-0.08	0.08	0.53	-0.07
	120	0.07	-0.08	-0.11	0.07	0.52	-0.11
	125	0.06	-0.09	-0.15	0.06	0.51	-0.15
	130	0.04	-0.10	-0.19	0.05	0.50	-0.19
	135	0.03	-0.12	-0.22	0.03	0.48	-0.23
	140	0.01	-0.14	-0.25	0.01	0.46	-0.26
	145	-0.02	-0.17	-0.26	-0.01	0.44	-0.27
	150	-0.04	-0.19	-0.26	-0.04	0.41	-0.27
	155	-0.06	-0.21	-0.24	-0.06	0.39	-0.25
	160	-0.08	-0.23	-0.21	-0.08	0.37	-0.22
	165	-0.10	-0.25	-0.17	-0.10	0.35	-0.18
	170	-0.11	-0.26	-0.12	-0.11	0.34	-0.12
	175	-0.12	-0.27	-0.06	-0.12	0.33	-0.06
	180	-0.12	-0.27	0.00	-0.12	0.33	0.00

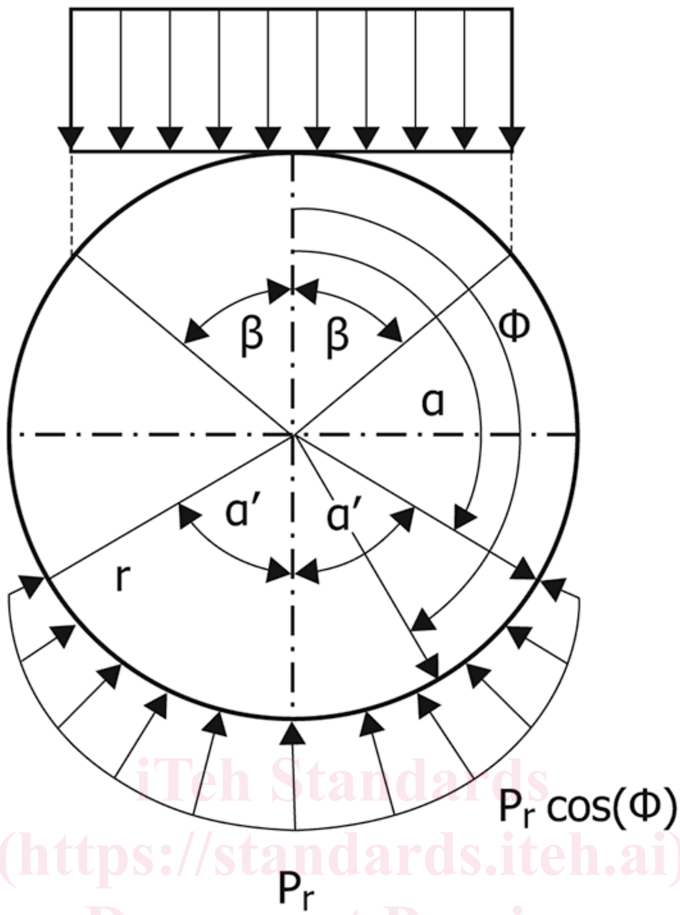

FIG. 3 Live Load Surcharge and Bedding Terminology

TABLE 3 Live Load Stress Distribution (Hurnung/Kittel Structural Analysis of Buried Pipes)

β=15 α'=45

	Live Load		
φ	Moment	Thrust	Shear
0	0.126	-0.0142	0
5	0.123	-0.0217	0.0884
10	0.111	-0.0441	0.174
15	0.0933	-0.0807	0.255
20	0.0721	-0.102	0.249
25	0.0517	-0.122	0.242
30	0.0323	-0.142	0.233
35	0.0139	-0.16	0.222
40	-0.00328	-0.177	0.21
45	-0.0191	-0.193	0.196
50	-0.0334	-0.207	0.18
55	-0.0462	-0.22	0.163
60	-0.0573	-0.231	0.145
65	-0.0666	-0.241	0.126
70	-0.0741	-0.248	0.105
75	-0.0797	-0.254	0.0842
80	-0.0834	-0.257	0.0625
85	-0.0851	-0.259	0.0404
90	-0.0849	-0.259	0.0179
95	-0.0826	-0.257	-0.00476
100	-0.0785	-0.252	-0.0274
105	-0.0724	-0.246	-0.0497
110	-0.0644	-0.238	-0.0717
115	-0.0546	-0.229	-0.0932
120	-0.0431	-0.217	-0.114
125	-0.0299	-0.204	-0.134
130	-0.0152	-0.189	-0.153
135	0.000965	-0.173	-0.335
140	0.0173	-0.157	-0.336
145	0.0325	-0.141	-0.332

150	0.0463	-0.128	-0.323
155	0.0584	-0.116	-0.311
160	0.0686	-0.105	-0.295
165	0.0768	-0.0972	-0.275
170	0.0827	-0.0913	-0.253
175	0.0863	-0.0877	-0.228
180	0.0875	-0.0865	-0.201

β=30 α'=45

	Live Load		
φ	Moment	Thrust	Shear
0	0.198	-0.0177	0
5	0.195	-0.0252	0.0907
10	0.183	-0.0476	0.179
15	0.165	-0.0841	0.261
20	0.141	-0.134	0.337
25	0.111	-0.195	0.402
30	0.0757	-0.265	0.455
35	0.0397	-0.301	0.435
40	0.00603	-0.335	0.411
45	-0.0251	-0.366	0.385
50	-0.0534	-0.394	0.355
55	-0.0787	-0.42	0.323
60	-0.101	-0.442	0.288
65	-0.12	-0.461	0.251
70	-0.135	-0.476	0.213
75	-0.147	-0.488	0.172
80	-0.154	-0.495	0.13
85	-0.159	-0.5	0.0876
90	-0.159	-0.5	0.0442
95	-0.156	-0.497	0.000471
100	-0.148	-0.489	-0.0433
105	-0.137	-0.478	-0.0867
110	-0.123	-0.464	-0.129
115	-0.105	-0.446	-0.171
120	-0.0832	-0.424	-0.212
125	-0.0584	-0.399	-0.251
130	-0.0307	-0.372	-0.288
135	-0.0000649	-0.341	-0.641
140	0.031	-0.31	-0.642
145	0.0599	-0.281	-0.635
150	0.086	-0.255	-0.619
155	0.109	-0.232	-0.596
160	0.128	-0.213	-0.566
165	0.144	-0.197	-0.529
170	0.155	-0.186	-0.487
175	0.162	-0.179	-0.44
180	0.164	-0.177	-0.389

β=45 α'=45

	Live Load		
φ	Moment	Thrust	Shear
0	0.236	-0.00626	0
5	0.232	-0.0138	0.0939
10	0.221	-0.0363	0.185
15	0.202	-0.073	0.271
20	0.178	-0.123	0.349
25	0.147	-0.184	0.417
30	0.112	-0.255	0.474
35	0.0724	-0.334	0.516
40	0.0306	-0.418	0.545
45	-0.0124	-0.504	0.557
50	-0.0537	-0.546	0.517
55	-0.0908	-0.583	0.472
60	-0.124	-0.616	0.424
65	-0.152	-0.644	0.373
70	-0.175	-0.667	0.318
75	-0.193	-0.685	0.262
80	-0.205	-0.697	0.203
85	-0.213	-0.705	0.143
90	-0.215	-0.707	0.0813
95	-0.212	-0.704	0.0194
100	-0.203	-0.695	-0.0427
105	-0.189	-0.681	-0.104
110	-0.17	-0.662	-0.165
115	-0.146	-0.638	-0.225
120	-0.117	-0.609	-0.283
125	-0.0836	-0.576	-0.339