

ASCE STANDARD

ASCE/CI

27-17

Standard Practice for Direct Design of Precast Concrete Pipe for Jacking in Trenchless Construction



Copyright American Society of Civil Engineers
Provided by IHS Markit under license with ASCE
No reproduction or networking permitted without license from IHS
Full document details: ASCE 27-17 2017



CONSTRUCTION
INSTITUTE



Documents
Document Sharing Hub

Licensee=University of Texas Revised Sub Account/5620001114, User=meros, kamelia
Not for Resale, 07/06/2018 02:05:08 MDT

ASCE STANDARD

ASCE/CI

27-17

Standard Practice for Direct Design of Precast Concrete Pipe for Jacking in Trenchless Construction



PUBLISHED BY THE AMERICAN SOCIETY OF CIVIL ENGINEERS

AVA Documents
Document Sharing Hub

Library of Congress Cataloging-in-Publication Data

Names: American Society of Civil Engineers, editor.

Title: ASCE standard ASCE/CI 27-17 : standard practice for direct design of precast concrete pipe for jacking in trenchless construction.

Other titles: Standard practice for direct design of precast concrete pipe for jacking in trenchless construction

Description: Reston, Virginia : American Society of Civil Engineers, [2017] | Includes bibliographical references and index.

Identifiers: LCCN 2016058354 (print) | LCCN 2016059895 (ebook) | ISBN 9780784413081 (print) | ISBN 9780784480373 (PDF)

Subjects: LCSH: Pipe, Concrete—Design and construction—Standards—United States. | Precast concrete—Standards—United States. | Trenchless construction—Standards—United States.

Classification: LCC TA447 .A83 2017 (print) | LCC TA447 (ebook) | DDC 625.7/34—dc23
LC record available at <https://lccn.loc.gov/2016058354>

Published by American Society of Civil Engineers

1801 Alexander Bell Drive

Reston, Virginia, 20191-4382

www.asce.org/bookstore | ascelibrary.org

This standard was developed by a consensus standards development process that has been accredited by the American National Standards Institute (ANSI). Accreditation by ANSI, a voluntary accreditation body representing public and private sector standards development organizations in the United States and abroad, signifies that the standards development process used by ASCE has met the ANSI requirements for openness, balance, consensus, and due process.

While ASCE's process is designed to promote standards that reflect a fair and reasoned consensus among all interested participants, while preserving the public health, safety, and welfare that is paramount to its mission, it has not made an independent assessment of and does not warrant the accuracy, completeness, suitability, or utility of any information, apparatus, product, or process discussed herein. ASCE does not intend, nor should anyone interpret, ASCE's standards to replace the sound judgment of a competent professional, having knowledge and experience in the appropriate field(s) of practice, nor to substitute for the standard of care required of such professionals in interpreting and applying the contents of this standard.

ASCE has no authority to enforce compliance with its standards and does not undertake to certify products for compliance or to render any professional services to any person or entity.

ASCE disclaims any and all liability for any personal injury, property damage, financial loss, or other damages of any nature whatsoever, including without limitation any direct, indirect, special, exemplary, or consequential damages, resulting from any person's use of, or reliance on, this standard. Any individual who relies on this standard assumes full responsibility for such use.

ASCE and American Society of Civil Engineers—Registered in U.S. Patent and Trademark Office.

Photocopies and permissions. Permission to photocopy or reproduce material from ASCE publications can be requested by sending an e-mail to permissions@asce.org or by locating a title in ASCE's Civil Engineering Database (<http://cedb.asce.org>) or ASCE Library (<http://ascelibrary.org>) and using the "Permissions" link.

Errata: Errata, if any, can be found at <https://doi.org/10.1061/9780784413081>.

Copyright © 2017 by the American Society of Civil Engineers.

All Rights Reserved.

ISBN 978-0-7844-1308-1 (soft cover)

ISBN 978-0-7844-8037-3 (PDF)

Manufactured in the United States of America.

23 22 21 20 19 18 17 1 2 3 4 5

ASCE STANDARDS

In 2014, the Board of Direction approved revisions to the ASCE Rules for Standards Committees to govern the writing and maintenance of standards developed by ASCE. All such standards are developed by a consensus standards process managed by the ASCE Codes and Standards Committee (CSC). The consensus process includes balloting by a balanced standards committee, and reviewing during a public comment period. All standards are updated or reaffirmed by the same process every five to ten years. Requests for formal interpretations shall be processed in accordance with Section 7 of ASCE Rules for Standards Committees, which are available at www.asce.org. Errata, addenda, supplements, and interpretations, if any, for this standard can also be found at www.asce.org.

Standard Practice for Direct Design of Precast Concrete Pipe for Jacking in Trenchless Construction, Standard ASCE/CI 27-17, was approved for publication by the Codes

and Standards Committee with a waiver from the rules for Codes and Standards Committees. The waiver is to allow reference to another standard without referring to an edition date. The committee's intent is that the standard being referenced is the latest edition available.

This standard has been prepared in accordance with recognized engineering principles and should not be used without the user's competent knowledge for a given application. The publication of this standard by ASCE is not intended to warrant that the information contained therein is suitable for any general or specific use, and ASCE takes no position respecting the validity of patent rights. The user is advised that the determination of patent rights or risk of infringement is entirely their own responsibility.

A complete list of currently available standards is available in the ASCE Library (<http://ascelibrary.org/page/books/s-standards>).

This page intentionally left blank

CONTENTS

ACKNOWLEDGMENTS	ix
PART I. GENERAL.	1
1.0 Scope.	1
1.2 Trenchless Construction	1
1.2.1 Jacking	1
1.2.2 Microtunneling	1
2.0 Applicable Documents.	1
2.1 ASTM (American Society for Testing and Materials)	1
2.2 AASHTO (American Association of State Highway and Transportation Officials)	2
2.3 ACI (American Concrete Institute)	2
2.4 ASCE (American Society of Civil Engineers)	2
2.5 AREMA (American Railway Engineering and Maintenance-of-Way Association)	2
3.0 Definitions	2
4.0 Notations	2
5.0 Summary of Practice.	4
PART II. DIRECT DESIGN METHOD FOR JACKED PRECAST CONCRETE PIPE INSTALLATIONS	5
6.0 General.	5
6.2 Design Submittals	5
7.0 General Design Requirements	5
7.1.1 Load Factors	5
7.1.2 Strength Reduction (Phi) Factors	5
7.1.3 Crack Control Factor	5
7.1.4 Process and Material Factors	5
8.0 Design Requirements of Owner	5
9.0 Design Requirements of Jacking Contractor	6
10.0 Design Requirements of Pipe Manufacturer	6
11.0 Materials	6
11.1 Concrete	6
11.2 Reinforcement	6
11.3 Joint Cushioning	6
12.0 Transverse Loads	7
12.1 Dead Load	7
12.2 Earth Load	7
12.3 Fluid Load and Pressure	7
12.4 Live Loads	8
12.5 Additional Earth Fill or Surface Surcharge Loads	8
13.0 Pressure Distribution for Transverse Loads (Fig. 13-1a–g).	8
13.1 Dead Load	8
13.1 Earth Load	8
13.3 Fluid Loads and Pressure	8
13.4 Live Loads	8
13.5 Additional Earth Fill Weight and Surcharge Loads	8
14.0 Stress Analysis for Effects of Transverse Loads	8
14.3.1 Invert	8
14.3.2 Springline	8
14.3.3 Crown	8
15.0 Transverse Reinforcement	10
15.1 Reinforcement Arrangement	10
15.2 Flexural Reinforcement	10
15.2.3 Maximum Flexural Reinforcement	10
15.3 Crack Control	11
15.4 Shear Strength	12
15.5 Stirrups	12
15.5.2 Radial Tension Stirrups	12
15.5.3 Shear Stirrups	12
15.5.4 Extent of Stirrups	12



	15.5.5	Stirrup Anchorage	12
	15.6	Welds, Splices, and Development of Reinforcement	12
16.0		Design for Axial Forces from Jacking	13
	16.1	Maximum Permissible Contract Compressive Stress Produced by Jacking Thrust Force	13
	16.2	Design Maximum Permissible Jacking Thrust Force	13
	16.3	Design Angular Deviation from Straight Line and Associated Eccentricity of Jacking Thrust Force	13
	16.4	Approximate Radius of Bend Produced by Angular Deviation, θ	13
17.0		Nonreinforced Concrete Pipe	14
18.0		Pipe Designation	14

APPENDIX A: MANUFACTURING SPECIFICATION FOR PRECAST CONCRETE PIPE FOR JACKING IN TRENCHLESS CONSTRUCTION			15
A.1.0		Scope	15
A.2.0		Reference Documents	15
A.3.0		Terminology	15
A.4.0		Permissible Variations	15
	A.4.1	Outside Diameter	15
	A.4.2	Wall Thickness	15
	A.4.3	End Squareness	15
A.5.0		Marking	15
	A.5.1	Pipe Designation	15

APPENDIX B: GUIDELINES FOR JACKING OPERATIONS			17
B.1.0		General	17
B.2.0		Jacking Pit	17
B.3.0		Shields	17
B.4.0		Joints	18
B.5.0		Excavation	18
B.6.0		Jacking	18
B.7.0		Intermediate Jacking Stations	18
B.8.0		Lubrication and Coatings	18
	B.8.1	Lubrication	18
	B.8.2	Coatings	18
B.9.0		Reception Pit	18

APPENDIX C: GUIDELINES FOR ESTIMATING REQUIRED JACKING FORCE			19
C.1.0		General	19
C.2.0		Jacking Resistance	19
C.3.0		Lubrication	19
C.4.0		Jacking Operation	19

APPENDIX D: SI UNITS FOR NOTATION AND EQUATIONS			21
D.1.0		Scope	21
D.4.0		Notations	21
D.12.0		Transverse Loads	22
	D.12.1	Dead Load	22
	D.12.2	Earth Load	22
	D.12.3	Fluid Load and Pressure	23
	D.12.4	Live Loads	23
	D.12.5	Additional Earth Fill or Surface Surcharge Loads	24
D.13.0		Pressure Distribution for Transverse Loads (Fig. 13-1a-g)	24
	D.13.1	Dead Load	24
	D.13.2	Earth Load	24
	D.13.3	Fluid Loads and Pressure	24
	D.13.4	Live Loads	24
	D.13.5	Additional Earth Fill Weight and Surcharge Loads	24
D.14.0		Stress Analysis for Effects of Transverse Loads	24
	D.14.3.1	Invert	24
	D.14.3.2	Springline	24
	D.14.3.3	Crown	24
D.15.0		Transverse Reinforcement	

D.15.1	Reinforcement Arrangement.	25
D.15.2	Flexural Reinforcement	25
D.15.2.3	Maximum Flexural Reinforcement	25
D.15.3	Crack Control	25
D.15.4	Shear Strength	26
D.15.5	Stirrups.	26
D.15.5.2	Radial Tension Stirrups	26
D.15.5.3	Shear Stirrups	26
D.15.5.4	Extent of Stirrups	26
D.15.5.5	Stirrup Anchorage	26
D.15.6	Welds, Splices, and Development of Reinforcement	26
D.16.0	Design for Axial Forces from Jacking	26
D.16.1	Maximum Permissible Contact Compressive Stress Produced by Jacking Thrust Force	27
D.16.2	Design Maximum Permissible Jacking Thrust Force	27
D.16.3	Design Angular Deviation from Straight Line and Associated Eccentricity of Jacking Thrust Force	27
D.16.4	Approximate Radius of Bend Produced by Angular Deviation, θ	27
D.17.0	Nonreinforced Concrete Pipe	27
COMMENTARY		29
C1.0	Scope.	29
C2.0	Applicable Documents.	29
C3.0	Definitions	29
C4.0	Notations.	29
C6.0	General.	29
C7.0	General Design Requirements	29
C7.1.2	Strength Reduction (Phi) Factors	30
C7.1.3	Crack Control Factor	30
C8.0	Design Requirements of Owner.	30
C9.0	Design Requirements of Jacking Contractor	30
C10.0	Design Requirements of Pipe Manufacturer	31
C12.0	Transverse Loads	31
C12.2	Earth Loads	31
C12.3	Fluid Load and Pressure.	32
C12.4	Live Loads.	32
C12.5	Additional Earth Fill or Surface Surcharge Loads	32
C13.0	Pressure Distribution for Transverse Loads.	32
C14.0	Stress Analysis for Effects of Transverse Loads	32
C15.0	Transverse Reinforcement	32
C15.2	Flexural Reinforcement	32
C15.2.3	Maximum Flexural Reinforcement	32
C15.3	Crack Control	33
C15.4	Shear Strength	33
C15.5	Stirrups.	34
C15.5.2	Radial Tension Stirrups	34
C15.5.3	Shear Stirrups	34
C15.5.5	Stirrup Anchorage	34
C16.0	Design for Axial Forces from Jacking	34
C16.1	Maximum Permissible Contact Compressive Stress Produced by Jacking Thrust Force	34
C16.2	Design Maximum Permissible Jacking Thrust Force.	34
C16.3	Design Angular Deviation from Straight Line and Associated Eccentricity of Jacking Thrust Force	34
C16.4	Approximate Radius of Bend Produced by Angular Deviation, θ	34
INDEX		37

This page intentionally left blank

ACKNOWLEDGMENTS

The American Society of Civil Engineers (ASCE) acknowledges the work of the Direct Design of Buried Concrete Pipe Box Sections Standards Committee of the Construction Institute of

ASCE. This group comprises individuals from many backgrounds, including consulting engineering, research, construction, education, government, design, and private practice.

Direct Design of Buried Concrete Pipe Box Sections Standards Committee

Kim Spahn, P.E., M.ASCE, *Chair*
Josh Beakley, P.E.
Eric A. Carleton, P.E., M.ASCE
Oliver S. Delery Jr., P.E., F.ASCE
Steve DelloRusso, P.E.
Jeffrey I. Enyart, P.E., M.ASCE
R. Hartley Field
Curtiss W. Gilley, P.E., F.ASCE
Corey Lee Haeder, P.E., M.ASCE
Paul M. Heffern, P.E., M.ASCE
George W. Hodge II, P.E., M.ASCE
John M. Kurdziel, P.E., M.ASCE
Joe M. Lundy Jr., Aff.M.ASCE
Hugh Martin, P.E., M.ASCE

Timothy J. McGrath, P.E., F.ASCE
Wallace J. Munden, P.E., M.ASCE
Michael P. Murphy, P.E., M.ASCE
Charles R. Nelson, Ph.D., P.E., M.ASCE
David K. Nishimura, P.E.
James A. Nystrom
Edward C. Page, P.E., M.ASCE
Gerald R. Price, P.E., M.ASCE
Roman J. Selig III, A.M.ASCE
Enrico Stradiotto
Joseph P. Zicaro, P.E.
Jonathan C. Esslinger, P.E., F.ASCE, *ASCE Staff Contact*
Katerina Lachinova, *ASCE Staff Contact*

This page intentionally left blank

PART I GENERAL

1.0 SCOPE

1.1 This practice covers design and recommended installation procedures for precast concrete pipe for jacking in trenchless construction intended for the conveyance of sewage, industrial wastes, stormwater, and drainage, and for utilities and access ways.

1.2 Trenchless Construction. Trenchless construction is a method of installing pipe without excavating an open trench.

1.2.1 Jacking. Jacking is a trenchless construction technique in which prefabricated pipes are installed by pushing (jacking) them longitudinally into position, usually from a pit. The spoil material is removed either manually or mechanically through the pipe being installed.

1.2.2 Microtunneling. Microtunneling is a method of installing pipe by trenchless construction techniques behind a remotely controlled, steerable, guided, articulated boring machine that is connected to and followed by the pipe that is being installed by jacking. Excess spoil material is removed mechanically through the pipe being installed.

1.3 The exterior surface of the pipe shall not contain projections such as enlarged bells, unless special provisions are made.

1.4 The successful performance of concrete pipe installed using jacking techniques requires proper design by the engineer for loading conditions during and after installation. It requires skillful placement by the installing contractor utilizing methods that maintain jacking loads to acceptable levels and maintain acceptable levels of variance from established line and grade. It requires precise fabrication of the pipe by the manufacturer to the standards and tolerance levels specified.

1.5 Part II of this standard practice presents a direct design method for jacked pipe installations. This design and analysis method considers the interaction between the pipe and surrounding soil and/or grout envelope in determining longitudinal loads developed during jacking, as well as transverse pressure distributions and circumferential moment, thrust, and shear in the pipe wall. A procedure for calculating the required reinforcement in the pipe wall is included.

1.6 Appendix A of this standard practice presents manufacturing requirements for precast concrete pipe intended for use in trenchless construction installed by jacking methods.

1.7 Appendix B of this standard practice presents guidelines for jacking operations.

1.8 Appendix C of this standard practice presents guidelines for estimating required jacking force.

1.9 This standard practice may be used as a reference by the owner and the owner's engineer in preparing project specifications.

1.10 The design procedures given in this standard practice are intended for use by engineers who are familiar with the installation and pipe characteristics that affect the structural behavior of jacked concrete pipe installations and the significance of the installation requirements. Before applying the design procedures given in Part II, the engineer should review the guidance and requirements given in other sections of this standard practice and its accompanying commentary.

1.11 The values of dimensions and quantities are expressed in inch-pound (English) units, which are to be regarded as standard. Where English unit values are converted to SI unit values they are presented in parentheses or a section following the English units. For clarity, Appendix D repeats the notation and contains the full translation of equations to SI units. The use of SI units is in accord with ASTM Practice E 380. SI units expressed in parentheses and in Appendix D are supplied for information only and are not part of this standard practice.

Note 1: Some of the applicable standards referenced may have a double designation (Axxx/AxxxM) or separate inch-pound (English) and SI (metric) unit editions. Only the inch-pound unit edition of a standard is listed in this practice.

Note 2: SI (metric) unit editions of ASTM standards on precast concrete pipe use the units of cm^2/m to denote steel reinforcement cross-sectional area, which is an acceptable, but not a preferred, SI unit.

2.0 APPLICABLE DOCUMENTS

2.1 ASTM (American Society for Testing and Materials)

2.1.1 A 1064/A 1064M Standard Specification for Carbon-Steel Wire and Welded Wire Reinforcement, Plain and Deformed, for Concrete

2.1.2 A 615/A 615M Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement

2.1.3 C 76 Specification for Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe

2.1.4 C 822 Definitions of Concrete Pipe and Related Products



2.1.5 C 985 Specification for Nonreinforced Concrete Specified Strength Culvert, Storm Drain, and Sewer Pipe

2.1.6 C 1417 Specification for Manufacture of Reinforced Concrete Sewer, Storm Drain, and Culvert Pipe for Direct Design

2.1.7 D 2487 Classification of Soils for Engineering Purposes (Unified Soil Classification System)

2.1.8 D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedures)

2.1.9 E 380 Practice for Use of the International System of Units (SI) the Modernized Metric System

2.2 AASHTO (American Association of State Highway and Transportation Officials)

2.2.1 Standard Specifications for Highway Bridges and Structures

2.3 ACI (American Concrete Institute)

2.3.1 ACI 318 Building Code Requirements for Reinforced Concrete and Commentary

2.4 ASCE (American Society of Civil Engineers)

2.4.1 ASCE 15-98 Standard Practice for Direct Design of Buried Precast Concrete Pipe Using Standard Installations

2.5 AREMA (American Railway Engineering and Maintenance-of-Way Association)

2.5.1 Manual for Railway Engineering

3.0 DEFINITIONS

3.1 For definitions of terms relating to concrete pipe, see ASTM Definitions C 822 and Fig. 3-1.

3.2 For terminology related to soil classifications, see ASTM Classification D 2487 and ASTM Practice D 2488.

3.3 For terminology and definition of terms relating to structural design, see AASHTO Standard Specifications for Highway Bridges and Structures.

3.4 Fig. 3-1 illustrates the definition and limits of the terms bottom, invert, crown, top, springline, and diameter of pipe as used in this standard practice.

4.0 NOTATIONS

The following symbols are used in this standard practice:

A_p = contact area between joint packing and concrete surface with no joint separation, in.² (mm²);

A'_p = contact area between joint packing and concrete surface with joint separation, in.² (mm²);

A_s = area of tension reinforcement required in length b , in.²/ft (mm²/m);

A_{si} = area of total inner cage reinforcement required in length b , in.²/ft (mm²/m);

A_{so} = area of total outer cage reinforcement required in length b , in.²/ft (mm²/m);

A_{vr} = area of stirrup reinforcement required to resist radial tension forces, in.²/ft (mm²/m) in each line of stirrups at circumferential spacing s_v ;

A_{vs} = area of stirrup reinforcement required to resist shear, in.²/ft (mm²/m) in each line of stirrups at circumferential spacing s_v ;

a = length (thickness) of joint packing, in. (mm);

B_{Th} = maximum span of tunnel bore for jacked pipe, in. (mm);

B_{Tv} = maximum rise of tunnel bore for jacked pipe including pipe dimension plus overbore, in. (mm);

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

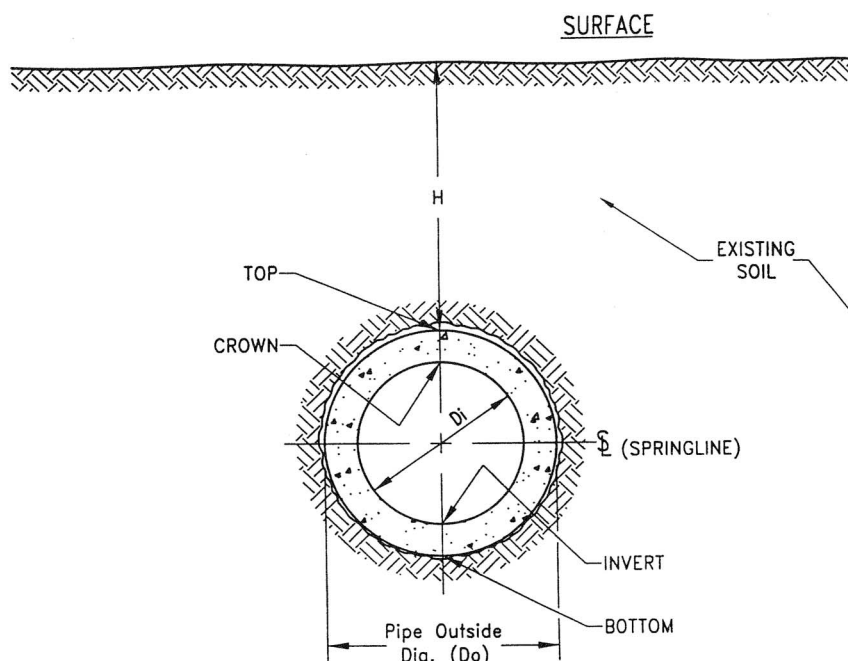


FIGURE 3-1. Jacked Pipe/Installation Terminology

- b = width of section that resists stress, in. (mm); taken as 12 in. (English units) and taken as 1,000 mm (SI units);
 b = unit length of pipe, ft (m); taken as 1 ft (English units) and taken as 1 m (SI units);
 C_{mc} = circumferential moment coefficient for pipe crown;
 C_{mi} = circumferential moment coefficient for pipe invert;
 C_{ms} = circumferential moment coefficient for pipe springline;
 C_{nc} = circumferential thrust coefficient for pipe crown;
 C_{ni} = circumferential thrust coefficient for pipe invert;
 C_{ns} = circumferential thrust coefficient for pipe springline;
 C_{nv} = circumferential thrust coefficient at location of critical shear on pipe;
 C_v = circumferential shear coefficient at location of critical shear on pipe;
 C_1 = crack control coefficient for type of reinforcement;
 c = soil cohesion, lbs/ft² (N/m²);
 D_i = inside diameter of pipe, in. (mm);
 D_m = mean diameter of pipe, in. (mm);
 D_o = outside diameter of pipe, in. (mm);
 D_{po} = outside diameter of joint packing ring, in. (mm);
 DL_{ut} = test D -load that cracks the nonreinforced concrete pipe, lbs/linear ft/ft of internal diameter (N/linear m/mm of internal diameter);
 D_T = width of tunnel, in. (mm);
 d = distance from compression face to centroid of tension reinforcement, in. (mm);
 E_c = design modulus of elasticity of concrete pipe wall, psi (MPa);
 E_p = design modulus of elasticity of joint cushioning material, psi (MPa);
 e = eccentricity of jacking load, in. (mm);
 e_k = kern eccentricity of pipe cross-section, in. (mm);
 F_c = factor for effect of curvature on diagonal tension (shear) strength in curved components;
 F_{cr} = crack width control factor for adjusting crack control relative to average maximum crack width of 0.01 in. (0.3 mm) at 1 in. (25 mm) from the tension reinforcement when $F_{cr} = 1.0$;
 F_d = factor for crack depth effect resulting in increase in diagonal tension (shear) strength with decreasing d ;
 F_N = coefficient for effect of circumferential thrust on shear strength;
 F_{rp} = factor for process and materials that affect the radial tension strength of pipe;
 F_{rt} = factor for pipe size effect on radial tension strength;
 F_v = factor for crack depth effect resulting in increase in diagonal tension (shear) strength with decreasing d ;
 F_{vp} = factor for process and materials that affect the shear strength of pipe;
 f'_c = design compressive strength of concrete, lbs/in.² (MPa);
 f_{mr} = modulus of rupture for nonreinforced concrete pipe, lbs/in.² (MPa);
 f_p = compressive stress on contact surface at joint cushioning or joint thrust ring, psi (MPa);
 f_{p1} = compressive stress on contact surface when jacking force is concentric (see Fig. 16-1a), psi (MPa);
 f_{p1m} = maximum allowed value of f_{p1} , psi (MPa);
 f_{p2} = compressive stress on contact surface at point of greatest stress when jacking forces vary from concentric (see Fig. 16-1b), psi (MPa);
 f_{p2m} = maximum allowed value of f_{p2} , psi (MPa);
 f_s = maximum service load stress of reinforcing steel for crack control, lbs/in.² (MPa);
 f_v = maximum developable strength of stirrup material, lbs/in.² (MPa);
 f_y = design yield strength of reinforcement, lbs/in.² (MPa);
 H = design height of earth above top of pipe, ft (m);
 HAF = horizontal arching factor, ratio of total horizontal force from lateral soil pressure acting on pipe to the weight of the column of earth over the horizontal span of the excavated tunnel;
 HAF_R = reduced horizontal arching factor associated with VAF_R ;
 h = overall thickness of member (wall thickness), in. (mm);
 h_p = width of contact surface for joint cushioning at jacking pipe joints (see Fig. 16-1), in. (mm);
 i = coefficient for effect of axial force at service load stress, f_s ;
 K = earth pressure ratio on sliding plane;
 K_2 = ratio of lateral force to vertical load on jacked pipe;
 k_{mr} = coefficient for determining modulus of rupture of nonreinforced concrete pipe;
 L = length of pipe, in. (mm);
 L_t = width of pipe subjected to unit load (force), ft (m);
 LFJ_1 = load factor for jacking thrust-concentric load causing uniform stress;
 LFJ_2 = load factor for jacking thrust-eccentric load causing nonuniform stress;
 l_0 = total additional arc length beyond calculated arc lengths requiring stirrups, in. (mm);
 M_{nu} = factored circumferential moment acting on length b as modified for effects of compressive or tensile thrust, in.-lbs/ft (Nmm/m);
 M_s = service load circumferential bending moment acting on length b , in.-lbs/ft (Nmm/m);
 M_u = factored circumferential moment acting on length b , in.-lbs/ft (Nmm/m);
 N_s = circumferential thrust acting on length b , service load condition (+ when compressive, – when tensile), lbs/ft (N/m);
 N_u = factored circumferential thrust acting on length b (+ when compressive, – when tensile), lbs/ft (N/m);
 n = number of layers of reinforcement in a cage, 1 or 2;
 P_{eh} = total lateral earth force acting on pipe, lbs/ft (N/m);
 P_j = total jacking force, lbs (N);
 P_{jlm} = maximum allowable jacking thrust force for uniform stress, lbs (N);
 P_{jnm} = maximum allowable jacking thrust force for nonuniform stress, lbs (N);
 p_L = live load acting on pipe, lbs/ft² (N/m²);
 p_{sur} = surcharge load acting on pipe, lbs/ft² (N/m²);
 r = radius of curvature produced by angular deviation at joints, in. (mm);
 r_m = mean radius of pipe, in. (mm);
 r_s = radius of the inside reinforcement, in. (mm);
 s_l = spacing of circumferential reinforcement, in. (mm);
 s_v = circumferential spacing of stirrups, in. (mm);
 t_b = clear cover over reinforcement, in. (mm);
 V_b = basic shear strength of length b at critical section where $M_{nu}/(V_u d) \geq 3.0$, lbs/ft (N/m);
 V_c = nominal shear strength provided by concrete in length b , lbs/ft (N/m);
 V_u = factored shear force acting on length b , lbs/ft (N/m);
 V_{uc} = factored shear force acting on length b at critical section where $M_{nu}/(V_{ud}) = 3.0$, lbs/ft (N/m);
 VAF = vertical arching factor, ratio of earth load on pipe, W_e , to the weight of the column of earth over the horizontal span of the excavated tunnel;
 VAF_R = reduced vertical arching factor to account for cohesion;
 W = general term for weights or loads acting on pipe including those listed immediately following;

W_e = total weight of earth acting on pipe, lbs/ft (N/m);
 W_f = total weight of fluid acting on pipe, lbs/ft (N/m);
 W_L = total live load (force) acting on pipe, lbs/ft (N/m);
 W_p = total weight of pipe, lbs/ft (N/m);
 W_{sur} = total surcharge load (force) acting on pipe, lbs/ft (N/m);
 w = unit weight of soil, lbs/ft³ (N/m³);
 z = partial diameter of contact surface that is separated (i.e., has zero contact stress) (see Fig. 16-1b), in. (mm);
 α = coefficient calculated from Eq. 12-3;
 β = bedding angle (see Fig. 13-1), degrees;
 ρ = ratio of reinforcement area to concrete area;
 θ = calculated angular deviation from straight line (Eq. 16-9), degrees;
 θ_v = angle from invert locating point of critical shear where $M_{nu}/(V_u d) = 3.0$;
 μ' = coefficient of friction between overfill and trench walls and coefficient of friction on a sliding plane;
 ϕ_f = strength reduction factor for flexure;
 ϕ_j = capacity reduction factor for compression produced by jacking thrust;
 ϕ_{mr} = strength reduction factor for modulus of rupture for nonreinforced concrete pipe;
 ϕ_r = strength reduction factor for radial tension; and
 ϕ_v = strength reduction factor for shear.

5.0 SUMMARY OF PRACTICE

5.1 The Direct Design Method accounts for the interaction between the pipe and soil or grout envelope in determining loads and distribution of earth pressure on buried pipe in addition to longitudinal loads due to jacking. The loads and pressure distributions are used to calculate circumferential moment, thrust, and shear in the wall to determine required reinforcement.

5.2 The design of a concrete pipe for a particular jacking installation is based on the assumption that the specified design parameters will be achieved during construction of the installation.

5.3 The structural design of concrete pipe is based on a limit state design procedure that accounts for strength and serviceability criteria and is consistent with the procedures in Section 17 of the AASHTO Standard Specifications for Highway Bridges and Structures. The design criteria include structural aspects, such as circumferential flexure, thrust, shear, and radial tension strengths; crack width control; longitudinal thrust produced by jacking; and requirements for handling and installation.