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Standard Guidelines for the Design, Installation, and Operation and Maintenance of Urban Stormwater Systems

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Standard Guidelines for the Design of Urban Stormwater Systems

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PUBLISHED BY THE AMERICAN SOCIETY OF CIVIL ENGINEERS

Library of Congress Cataloging-in-Publication Data

Names: American Society of Civil Engineers, editor.
Title: ASCE standard, ASCE/EWRI, 45-16, 46-16, 47-16 : standard guidelines for the design of urban stormwater systems.
Other titles: Standard guidelines for the design of urban stormwater systems
Description: Reston, Virginia : American Society of Civil Engineers, [2017] | Includes bibliographical references and index.
Identifiers: LCCN 2016058532 | ISBN 9780784413319 (soft cover : alk. paper) | ISBN 9780784480199 (PDF)
Subjects: LCSH: Storm sewers–Standards–United States.
Classification: LCC TD665 .A79 2017 | DDC 628/.212021873–dc23 LC record available at https://lccn.loc.gov/2016058532

Published by American Society of Civil Engineers
1801 Alexander Bell Drive
Reston, Virginia, 20191-4382
www.asce.org/bookstore | ascelibrary.org

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Errata: Errata, if any, can be found at https://doi.org/10.1061/97807844-1331-9.

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All Rights Reserved.
ISBN 978-0-7844-1331-9 (soft cover)
ISBN 978-0-7844-8019-9 (PDF)
Manufactured in the United States of America.

24 23 22 21 20 19 18 17 1 2 3 4 5

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Standard Guidelines for the Design of Urban Stormwater Systems

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PREFACE

The *Standard Guidelines for the Design of Urban Stormwater Systems* is a companion to the *Standard Guidelines for the Installation of Urban Stormwater Systems* and *Standard Guidelines for the Operation and Maintenance of Urban Stormwater Systems*. These standard guidelines were developed by the Urban Drainage Standards Committee, which is responsible to the Environmental and Water Resources Institute of the American Society of Civil Engineers.

The provisions of this document are written in permissive language and, as such, offer to the user a series of options or instructions but do not prescribe a specific course of action. Significant judgment is left to the user of this document.

These standard guidelines may involve hazardous materials, operations, and equipment. These standard guidelines do not purport to address the safety problems associated with its application. It is the responsibility of whoever uses these standard guidelines to establish appropriate safety and health practices and to determine the applicability of regulatory and nonregulatory limitations.

ACKNOWLEDGMENTS

The American Society of Civil Engineers acknowledges the work of the Urban Drainage Standards Committee of the Environmental and Water Resources Institute of ASCE.

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CHAPTER 1
SCOPE

The intent of these standard guidelines is to present design guidance for urban stormwater systems. It updates ASCE/EWRI 45-05 *Standard Guidelines for the Design of Urban Stormwater Systems* with material developed within the past eight years. The collection, management, and conveyance of urban surface waters are within the purview of these standard guidelines for applications such as airports, roads, and other transportation systems; and industrial, commercial, residential, and recreation areas. This document is intended for guidance during the design phase.

These standard guidelines do not address applications, such as agricultural drainage, landfills, and injection systems. Combined Sewer Overflows (CSOs) also are not addressed, because they are environmentally unacceptable as a new standard of practice in the United States.

Both SI units and customary units are used throughout the guidelines for the narrative, figures, and tables. The formulas are written in dual units or written separately to show the use of either SI units or customary units.

1.1 APPLICABLE STANDARDS

The standards listed as follows are available from the offices of the cited organization: American Association of State Highway Officials (AASHTO) in Washington DC; American Society of Civil Engineers (ASCE) in Reston, VA; American National Standards Institute/American Water Works Association documents from AWWA in Denver; and ASTM International (ASTM) in West Conshohocken, PA. The standards are mentioned in these guidelines at the sections in which they are applicable.

The ASTM standard and comparable AASHTO standard for a product are commonly identical; however, there may be some differences, especially when AASHTO standards lag behind ASTM standard revisions. If there is a separate metric edition of a standard, its designation includes the letter M (e.g., C507M).

American Association of State Highway and Transportation Officials (AASHTO), *Standard Specifications for Highway Bridges*, AASHTO HB-17, 17th Ed., 2002.

AASHTO, *Standard Specification for Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes*, M145-91, 2004.

AASHTO, *Standard Specification for Bituminous Coated Corrugated Metal Culvert Pipe and Pipe*, M190-04, 2004.

AASHTO, *Standard Specification for Corrugated Aluminum Alloy Structural Plate for Field-Bolted Pipe, Pipe-Arches, and Arches*, M219-92, 2004.

AASHTO, *Standard Practice for Corrugated Polyethylene Drainage Pipe*, AASHTO M252-09, 2009.

AASHTO, *Standard Specification for Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers*, M259/M259M-11, 2011.

AASHTO, *Standard Specification for Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers with Less Than 2 Feet (0.6 m) of Cover Subjected to Highway Loadings*, M273/M273M-11, 2011.

AASHTO, *Standard Practice for Corrugated Polyethylene Pipe 300- to 1500-mm (12- to 60-in.)*, M294-10, 2010.

AASHTO, *Standard Specification for Poly(Vinyl Chloride) (PVC) Profile Wall Drain Pipe and Fittings Based on Controlled Inside Diameter*, M304-11, 2011.

AASHTO, *Standard Method of Test for Moisture-Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and a 305-mm (12-in.) Drop*, T 99-10, 2010.

American National Standards Institute, Inc./Hydraulic Institute (ANSI/HI) (1998). *American National Standard for Pump Intake Design*, Hydraulic Institute, Parsippany, New Jersey.

American Society of Civil Engineers (ASCE), *Standard Practice for Direct Design of Buried Precast Concrete Pipe Using Standard Installations*, ASCE Standard 15-98, ASCE, 1998.

ASCE, *Standard Practice for Direct Design of Precast Concrete Box Sections*, Standard 26-97, 1997.

ASCE, *Standard Practice for Direct Design of Precast Concrete Pipe for Jacking in Trenchless Construction*, Standard 27-00, 2000.

ASCE, *Standard Practice for Direct Design of Precast Concrete Box Sections for Jacking in Trenchless Construction*, Standard 28-00, 2000.

ASCE, *Comprehensive Transboundary Water Quality Management Agreement*, Standard 33-09, 2009.

ASTM International (ASTM), *Standard Specification for Corrugated Steel Structural Plate, Zinc-Coated, for Field-Bolted Pipe, Pipe-Arches, and Arches*, A761/761M-04, 2009.

ASTM, *Standard Practice for Structural Design of Corrugated Steel Pipe, Pipe-Arches, and Arches for Storm and Sanitary Sewers and Other Buried Appurtenances*, A796/A796M-10, 2010.

ASTM, *Standard Specification for Corrugated Steel Box Culverts*, A964/A964M-03, 2011.

ASTM, *Standard Specification for Composite Ribbed Steel Pipe, Precoated and Polyethylene Lined for Gravity Flow Sanitary Sewers, Storm Sewers, and Other Special Applications*, A978/A978M-11, 2011.

ASTM, *Standard Specification for Corrugated Aluminum Alloy Structural Plate for Field-Bolted Pipe, Pipe-Arches, and Arches*, B746/B746M-02, 2012.

ASTM, *Standard Specification for Nonreinforced Concrete Sewer, Storm Drain, and Culvert Pipe*, C14-07/C14M-07, 2007.

ASTM, Standard Specification for Concrete Pipe for Irrigation or Drainage, C118-05a/C118M-05a, 2005.

ASTM, Standard Specification for Reinforced Concrete Low-Head Pressure Pipe, C361-08/C361M-08, 2008.

ASTM, *Standard Specification for Nonreinforced Concrete Irrigation Pipe with Rubber Gasket Joints*, C505-05a/C505M-05a, 2005.

ASTM, *Standard Specification for Reinforced Concrete Elliptical Culvert, Storm Drain, and Sewer Pipe*, C507-11/C507M-11, 2011.

ASTM, *Standard Specification for Nonreinforced Concrete Specified Strength Culvert, Storm Drain, and Sewer Pipe*, C985-04/C985M-04, 2010.

ASTM, *Standard Specification for Precast Reinforced Concrete Monolithic Box Sections for Culverts, Storm Drains, and Sewers*, C1433/C1433M-10, 2010.

ASTM, *Standard Specification for Precast Reinforced Concrete Monolithic Box Sections for Culverts, Storm Drains, and Sewers Designed According to AASHTO LRFD*, C1577-13.

ASTM, *Standard Specification for Joints for Concrete Box, Using Rubber Gaskets*, C1677-11A.