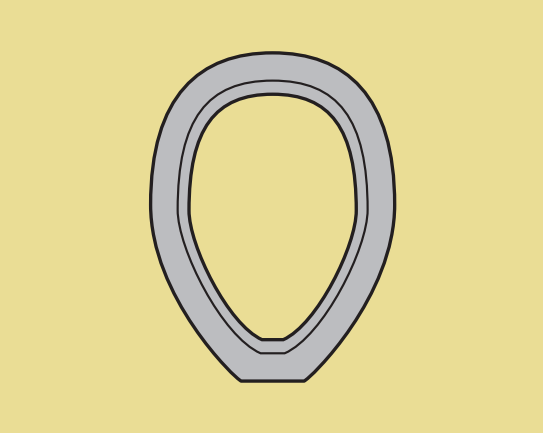
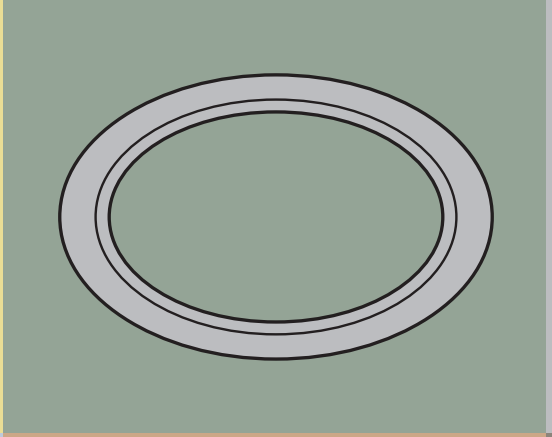
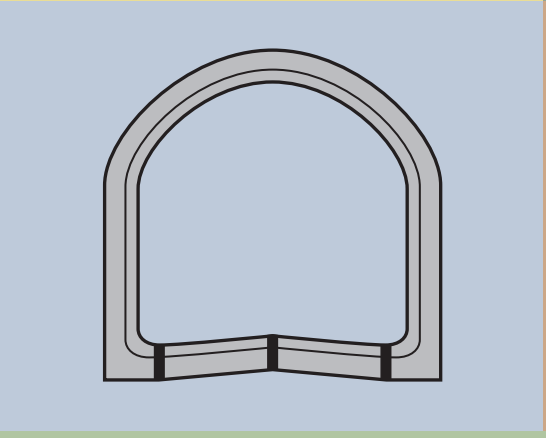
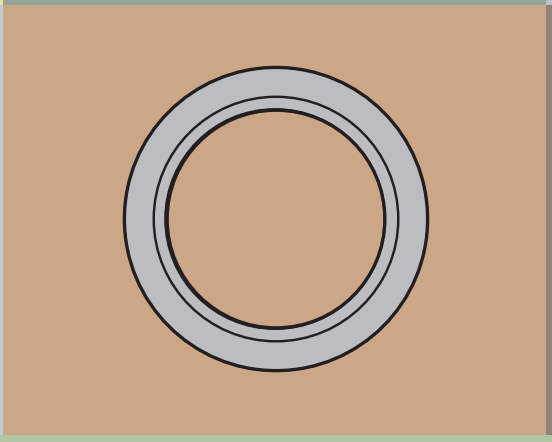
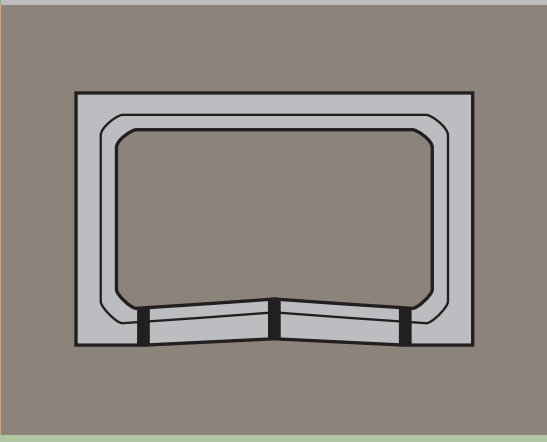






ASCE Manuals of Reports on Engineering Practice No. **145**

Design of Close-Fit Liners for the Rehabilitation of Gravity Pipes

Pipeline Infrastructure Committee

Edited by
Norman E. "Ed" Kampbell, P.E.
Jadranka Simicevic

ASCE

NASSCO

UESI UTILITY ENGINEERING & SURVEYING INSTITUTE

ASCE Manuals of Reports on Engineering Practice No. 145

Design of Close-Fit Liners for the Rehabilitation of Gravity Pipes

Prepared by
Pipeline Infrastructure Committee of the
Pipeline Division of the
American Society of Civil Engineers

Edited by
Norman E. "Ed" Kampbell, P.E.
Jadranka Simicevic

Published by the American Society of Civil Engineers

Library of Congress Cataloging-in-Publication Data

Names: Kampbell, Norman E., editor. | Simicevic, Jadranka, editor.
Title: Design of close-fit liners for the rehabilitation of gravity pipes / edited by Norman E. "Ed" Kampbell, P.E., Jadranka Simicevic.
Description: Reston, Viginia : American Society of Civil Engineers, [2021] | Series: ASCE manual and reports on engineering practice ; no. 145 | "Prepared by the Pipeline Infrastructure Committee of UESI." | Includes bibliographical references and index. | Summary: "MOP 145 provides a comprehensive explanation of the design of flexible, close-fit linings for the renewal or rehabilitation of pipes designed for gravity flow such as sanitary sewers, culverts, and storm sewers"-- Provided by publisher.
Identifiers: LCCN 2021015568 | ISBN 9780784415801 (print) | ISBN 9780784483558 (ebook)
Subjects: LCSH: Water-pipes--Linings--Design and construction. | Sewage lagoons--Linings--Design and construction. | Sewer-pipe--Maintenance and repair.
Classification: LCC TD491 .D47 2021 | DDC 628/.24--dc23
LC record available at https://lccn.loc.gov/2021015568

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

Any statements expressed in these materials are those of the individual authors and do not necessarily represent the views of ASCE, which takes no responsibility for any statement made herein. No reference made in this publication to any specific method, product, process, or service constitutes or implies an endorsement, recommendation, or warranty thereof by ASCE. The materials are for general information only and do not represent a standard of ASCE, nor are they intended as a reference in purchase specifications, contracts, regulations, statutes, or any other legal document. ASCE makes no representation or warranty of any kind, whether express or implied, concerning the accuracy, completeness, suitability, or utility of any information, apparatus, product, or process discussed in this publication, and assumes no liability therefor. The information contained in these materials should not be used without first securing competent advice with respect to its suitability for any general or specific application. Anyone utilizing such information assumes all liability arising from such use, including but not limited to infringement of any patent or patents.

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

Photocopies and permissions. Permission to photocopy or reproduce material from ASCE publications can be requested by sending an email to permissions@asce.org or by locating a title in the ASCE Library (https://ascelibrary.org) and using the "Permissions" link.

***Errata:* Errata, if any, can be found at https://doi.org/10.1061/9780784415801.**

Copyright © 2021 by the American Society of Civil Engineers.
All Rights Reserved.

ISBN 978-0-7844-1580-1 (print)
ISBN 978-0-7844-8355-8 (PDF)

Manufactured in the United States of America.

27 26 25 24 23 22 21 1 2 3 4 5

MANUALS AND REPORTS ON ENGINEERING PRACTICE

(As developed by the ASCE Technical Procedures Committee, July 1930, and revised March 1935, February 1962, and April 1982)

A manual or report in this series consists of an orderly presentation of facts on a particular subject, supplemented by an analysis of limitations and applications of these facts. It contains information useful to the average engineer in his or her everyday work, rather than findings that may be useful only occasionally or rarely. It is not in any sense a "standard," however, nor is it so elementary or so conclusive as to provides a "rule of thumb" for nonengineers.

Furthermore, material in this series, in distinction from a paper (which expresses only one person's observations or opinions), is the work of a committee or group selected to assemble and express information on a specific topic. As often as practicable the committee is under the direction of one or more of the Technical Divisions and Councils, and the product evolved has been subjected to review by the Executive Committee of the Division or Council. As a step in the process of this review, proposed manuscripts are often brought before the members of the Technical Divisions and Councils for comment, which may serve as the basis for improvement. When published, each manual shows the names of the committees by which it was compiled and indicates clearly the several processes through which it has passed in review, so that its merit may be definitely understood.

In February 1962 (and revised in April 1982), the Board of Direction voted to establish a series titled "Manuals and Reports on Engineering Practice" to include the manuals published and authorized to date, future Manuals of Professional Practice, and Reports on Engineering Practice. All such manual or report material of the Society would have been refereed in a manner approved by the Board Committee on Publications and would be bound, with applicable discussion, in books similar to past manuals. Numbering would be consecutive and would be a continuation of present manual numbers. In some cases of joint committee reports, bypassing of journal publications may be authorized.

A list of available Manuals of Practice can be found at http://www.asce.org/bookstore.

CONTENTS

PREFACE ..... **vii**

ACKNOWLEDGMENTS ..... **ix**

1. INTRODUCTION **1**
1.1 Background 1
1.2 About This Manual 3
References 4

2. SOIL–PIPE STRUCTURE INTERACTION SYSTEMS **5**
2.1 Existing Pipe Structure under External Load 5
2.2 Loads on Buried Pipe Structures (Before Lining) 12
2.3 Loads on Close-Fit Liner Installed in Pipe 21
References 22

3. CONDITION ASSESSMENT **25**
3.1 Introduction 25
3.2 Gravity Pipeline Inspection Technologies 25
3.3 Primary Pipeline Inspection Technologies 26
3.4 Secondary Pipeline Inspection Technologies 32
3.5 NASSCO Standards for Defect Coding: PACP, MACP, LACP 33
3.6 Geotechnical Investigations 34
References 35

4. LINER MATERIAL/SYSTEM ALTERNATIVES **37**
4.1 Introduction 37
4.2 Cured-in-Place Pipe 37
4.3 Fold and Form (Tight-Fit Thermoplastic Liners) 40
References 42

5. DESIGN CALCULATIONS **43**
5.1 Introduction 43
5.2 Liner Behavior under Groundwater Pressure 49
5.3 Liner Behavior under Deferred Deflection 60
5.4 Liner Behavior under Full Soil Overburden Pressure and Surface Loads 65
5.5 Liner Material Properties in Design Calculations 67
5.6 Soil Properties Used in Design Calculations 69
5.7 Load and Resistance Factor Design Factors 71
5.8 Design for State I 73

5.9 Design for State II 99
5.10 Design for State III 119
5.11 Final Notes 140
5.12 Notations 141
References 149

6. SUMMARY AND CONCLUSIONS 151

REFERENCED ASTM STANDARDS 153

APPENDIX: ACRONYMS AND UNIT AND CONVERSION FACTORS 155

GLOSSARY 157

INDEX 163

PREFACE

This Manual of Practice is intended to be a comprehensive and useful source of information for the design of flexible, close-fit linings for the renewal and/or rehabilitation of pipes designed for gravity flow, such as sanitary sewers, culverts, and storm sewers. This manual with its adoption by ASCE supersedes the use of "Appendix X1 Design Considerations" presented in the nonmandatory section of the ASTM Standard F-1216, which has been the default design method for circular pipes with no more than 10%ovality since its first publication in 1989. The design solution prescribed herein can be used for circular and noncircular geometries such as pipe-arch shapes and egg shapes (of all the various rise-to-span ratios), for elliptical-shaped pipes (horizontal and vertical) and box-shaped pipes (rectangular and square), and for other undefined site-specific shapes.

This manual is written in such a manner as to guide the design engineer in assessing the existing soil–structure interaction system, estimating the state of the stresses in that system, and designing the wall thickness of a close-fit flexible liner that will need to be installed to efficiently carry the loads that will likely come onto it after it is installed.

The contents of this manual represent the collected background and experience of many learned professionals active throughout the world in the evaluation and rehabilitation of the existing buried pipe structures.

This manual was produced under the guidance of Norman E. "Ed" Kampbell, task group chair. The authors are

Brian Dorwart
Norman E. "Ed" Kampbell
David Kozman
Lynn E. Osborn
Jadranka Simicevic

ACKNOWLEDGMENTS

Task Group Members on *Design of Close-Fit Liners for the Rehabilitation of Gravity Pipes*

Norman E. Kampbell, *Chair*	Rehabilitation Resource Solutions
Kelly Derr, *Vice Chair*	Brown & Caldwell
David Kozman, *Secretary*	HammerHead Trenchless
Brian Dorwart	Brierly Associates
Lynn Osborn	LEO Consulting
Jadranka Simicevic	JPS Consulting
John Struzziery	Town of Hull

Blue Ribbon Panel Reviewers

Ian Moore, Queens University
Olivier Thépot, Eau de Paris
John Schroeder, Hazen and Sawyer
Chris Macey, AECOM

NASSCO

NASSCO is honored to co-publish this Manual of Practice with UESI and ASCE. This effort began many years ago within NASSCO when Ed Kampbell, P.E., who had developed new design procedures for cured-in-place pipe (CIPP), suggested that NASSCO produce a CIPP design manual. After much discussion, it was agreed that ASCE would be a more appropriate organization to undertake this initiative.

Discussions with ASCE began even prior to UESI becoming ASCE's ninth institute. A work effort was started within the Pipeline Division's Trenchless Installation of Pipelines (TIPs) Committee, and after several years of writing, reviewing, and conversing, this Manual of Practice has become a reality.

NASSCO is currently collaborating with UESI and ASCE on more manuals for copublishing. Based on the success of this Manual of Practice, we see future opportunities for developing additional educational resources with UESI and ASCE and appreciate the opportunity to partner with UESI and ASCE to set standards for the assessment, maintenance, and rehabilitation of underground infrastructure.

Sheila Joy
Executive Director
NASSCO, Inc.

CHAPTER 1
INTRODUCTION

1.1 BACKGROUND

Many sources of information are available to the practicing engineers to turn to and collect the individual pieces of engineering information necessary to understand and apply the design of the various close-fit renewal and/or rehabilitation techniques for culvert, sanitary, and storm sewer pipes. However, what has been lacking to date is a single comprehensive document that places the state-of-the-art present-day design information into one source that is readily available to the consulting engineers and can be easily revised as new engineering knowledge on the subject becomes available.

Arriving at an appropriate design for the renewal of an existing buried pipe structure requires a markedly different approach than the design of a new buried pipe installation and is, in general, more difficult. This is because the type and magnitude of loading coming onto the liner other than groundwater pressure, if any, and how that loading is transferred to the new liner is governed by the in-place performance of the surrounding soil(s) and the existing pipe's current structural condition; or, in other words, it depends on the current state of the stresses, material properties, and contact conditions in the existing soil–structure interaction system.

In a new buried pipe installation design, the quality and extent of the local soil conditions can be addressed by the design engineer's choice of the embedment material to use, the effective width of the trench, compaction level of the embedment material(s), and any special structural details that need to be employed (e.g., stay in place shoring, geotextile wraps, special foundations) to contribute to a successful design life for the proposed buried pipe structure. The design engineer for a new pipe project can further overcome the challenges of the installation site by choosing between a rigid pipe material and a flexible pipe material to address the project site's specific installation and/or safety issues. In a pipe renewal design, the design engineer has to work with a pipe in a given condition and with the given choice of liner material and method of installation. The magnitude of loading coming onto the liner and how that loading is transferred to the new liner is governed by the in-place performance of the surrounding soil and the existing pipe's current structural condition; or, in other words, it depends on the current state of the stresses, material properties, and contact conditions in the existing soil–pipe interaction system.

> The real behavior of structures in contact with ground involves an interactive process beginning with the construction phase and ending with a state of balance after a period of adjustment of stresses and strains within the structure and within the ground influenced by the structure. (Thorburn 1985)

Design of lining systems suitable for a specific deteriorated pipe or culvert, therefore, relies on an understanding of the current state of stresses, strains, and deformations in the soil–pipe interaction system to be renewed. In 1976, the introduction of the Culvert Analysis and DEsign program provided a rational design method for culvert structures including culvert pipes and soil backfill that acknowledged the significant effects of the soil–structure interaction on the stability of buried culverts and the overlying pavement or surface structures. The results demonstrated that the structural fill surrounding the pipe and the pipe itself form a codependent composite structure. It is this composite structure that is undergoing the in situ renewal. This, in turn, implied that if the existing host pipe's visible structural damage (deterioration) has not compromised the soil support system (the surrounding soil has not eroded, for instance, through pipe defects into the pipe, leaving voids in the soil surround), the composite structure can still be cost-effectively maintained and rehabilitated. However, once the soil support system for a damaged pipe has been compromised or a total failure (pipe collapse) has occurred, the soil–structure interaction system has reached the end of its service life and must be replaced rather than renewed using a close-fit lining technique.

To date, the current practice for most engineers in North America has been to specify the design of a cured-in-place pipe (CIPP) liner using the nonmandatory design appendix in the ASTM CIPP installation standard F1216. When this standard was originally published in 1989, the authors no doubt felt that the engineering community needed some guidance for arriving at an appropriate wall thickness for the pipe being renewed by the installation of the CIPP liner. However, given the lack of engineering understanding (research) at that point in time regarding the behavior and design of a liner installed in an existing pipe, the nonmandatory design appendix borrowed from existing engineering theory on hydrostatic buckling (Timoshenko and Gere 1961) and new pipe installation design available at that time and adopted the division of the design analysis into two categories: fully deteriorated and partially deteriorated. The definitions creating these two categories were as follows: Partially deteriorated pipe—the original pipe can support the soil and the surcharge loads throughout the design life of the rehabilitated pipe. The soil adjacent to the existing pipe must provide adequate side support. The pipe may have longitudinal cracks and up to 10.0% distortion of the diameter. If distortion of the diameter is greater than 10.0%, alternative design methods were required. Fully deteriorated pipe—the original pipe is not structurally sound and cannot support soil and live loads or is expected to reach this condition over the design life of the rehabilitated pipe. This is evident when sections of the original pipe are missing, the pipe has lost its original shape, or the pipe has corroded due to the effects of the fluid, atmosphere, soil, or applied loads.

The 10% distortion in the previous definitions was a choice made in 1989 that was based on judgment, rather than testing and analysis. The definitions of the pipe's current condition state have remained unchanged since they were written in 1989.

Moving forward to today, many engineers and owners have essentially adopted what they have perceived to have been a *conservative* approach to the liner's wall thickness design. That approach is to routinely require the fully deteriorated design condition. The fully deteriorated design focuses on earth pressure buckling, which is unlikely to be a governing strength limit state for a liner in a fractured sewer (Law and Moore 2003) and yields unnecessary large liner thickness. When lining 8, 10, and 12 in. diameter pipes, the cost penalties associated with the price and the performance differences of the liner were seen as negligible; however, as the size and shape of the pipes being renewed have grown, the complexities of fit and finish have created a litany of negative impacts from this so-called conservative design approach. As a direct result of this *conservative* practice and its ensuing problems, there has been a significant amount of engineering research pursued as to how liners really perform when installed into various

existing pipe situations. This has generated an engineering knowledge base that has significantly improved the engineering understanding of how existing soil–structure interaction systems have performed in the past and how they will work in concert with the liner in the future.

Another drawback to the ASTM F1216 design appendix has been its limitation to only pipes with circular geometries exhibiting less than 10.0% distortion, leaving the practicing engineer to fend for himself or herself as to how to design noncircular geometries such as eggs, arches, and ellipses. Other issues that ASTM F1216 did not address are design for flexible structures such as corrugated steel and thermoplastic pipes (the method was developed for rigid pipes), no consideration of surface loading (vehicles), and no explicit consideration of soil deterioration (10% ovality induced in a fractured clay or concrete sewer can only result when there is soil deterioration).

Without any recent work to properly adapt the ongoing engineering research done elsewhere, the two F-1216 solutions have progressively lost support, and the industry has been looking toward the more sophisticated and technically correct analysis tools developed in Europe and Canada (e.g., Boot and Gumbel in England, Olivier Thépot for RERAU in France, and Ian Moore in Canada).

1.2 ABOUT THIS MANUAL

1.2.1 Purpose

The purpose of this Manual of Practice (MOP) is to provide guidance to the consulting engineers tasked with designing flexible close-fit liners for the renewal of existing gravity pipe applications in a form that is readily usable. Upon reading the manual, the consulting engineers should be able to understand and apply design procedures detailed in the manual to calculate the required liner thickness in deteriorated pipes for which these procedures have been developed and are applicable. In most cases, the closed-form solution is already available and where that is not the case, the finite-element analysis is recommended; in some cases, different rehabilitation options should be considered. The design guidance will no doubt need to be updated as the understanding for liners in pressure piping applications is developed and can be implemented herein.

In the meantime, the task group charged with this MOP's production advises the engineering community that the pressure pipe design guidance also contained in the ASTM standard F1216 has been found to be quite lacking and should not be employed as presented therein in the design of liners in pressure pipe applications.

1.2.2 Scope

This MOP covers the thickness design of flexible liners to be installed in a gravity-flow sewer or culvert pipe; the host pipe can be rigid or flexible and be circular or noncircular; the installation method is trenchless and yields close-fit lining, for example, cured-in-place lining or fold-and-form lining.

1.2.3 Document Organization

This manual contains six chapters, glossary, references, and one appendix, with material as follows:

- Chapter 1 provides the background information and explains the need for this manual and its purpose and scope.

- Chapter 2 describes pipe–soil structure interaction systems before rehabilitation, outlining the difference in the behavior of rigid and flexible buried structures under loading, including their different failure modes and main deterioration mechanisms. Current understanding of the loads that could act on the liner within host pipe is outlined.
- Chapter 3 discusses the condition assessment of site conditions and presents the pipe inspection methods available to collect and process the necessary data for successful liner design, and the geotechnical investigations performed as needed prior to liner design are described.
- Chapter 4 presents the lining options included in the scope of this manual, including a brief description of each method, principal installation, and associated standards where existing, selected physical properties, and some usually acknowledged advantages and limitations of each method.
- Chapter 5 is the main design chapter with several different design procedures for calculating the required liner thickness in three design states, with a distinction between rigid and flexible host pipe, and behavior of the liner under external groundwater pressure based on the shape of the host pipe. Different loading conditions (groundwater pressure, deferred deflection of the host pipe during the liner's service life, and earth and surface live loads) are discussed, explaining the liner behavior under such loading conditions, applicable design formulas, and limit states in the design. Each design procedure is described in detail and includes all necessary formulas to perform the calculations and the recommendations for selecting input parameters as needed. The Notation contains a complete list of symbols used for various parameters in the formulas and text of the manual in alphabetical order.
- Chapter 6 provides brief conclusions about the presented material in the manual and explains why the design approach is very different from the one that has been practiced based on the ASTM F1216.
- Glossary provides brief definitions or explanations of terms on subjects discussed in the manual.
- References list various publications referenced in the manual.
- Appendix includes the list of acronyms used in the manual, including abbreviations for organizations, methods, properties, and so on, and a short list of units and conversion factors.

REFERENCES

Law, T. C. M., and I. D. Moore. 2003. "Guidance on design of flexible liners to repair structurally compromised gravity flow sewers." In *Proc., Int. No-Dig Conf.* Las Vegas: North American Society for Trenchless Technology/International Society for Trenchless Technology.

Thorburn, S. 1985. "The real behaviour of structures—Soil structure interaction." *Struct. Eng.* 63 (2): 117.

Timoshenko, S. P., and J. M. Gere. 1961. *Theory of plastic stability*. 2nd ed. New York: McGraw-Hill.