ASCE Manuals and Reports on Engineering Practice No. 119

Buried Flexible Steel Pipe

Design and Structural Analysis

ASCE

ASCE Manuals and Reports on Engineering Practice No. 119

Buried Flexible Steel Pipe

Design and Structural Analysis

Prepared by
the Task Committee on Buried Flexible (Steel)
Pipe Load Stability Criteria & Design of
the Pipeline Division of
the American Society of Civil Engineers

Edited by
William R. Whidden, P.E.

American Society of Civil Engineers

Library of Congress Cataloging-in-Publication Data

Buried flexible steel pipe : design and structural analysis / prepared by the Task Committee on Buried Flexible (Steel) Pipe Load Stability Criteria & Design of the Pipeline Division of the American Society of Civil Engineers; edited by William R. Whidden.

p. cm.—(ASCE manuals and reports on engineering practice; no. 119)

Includes bibliographical references and index.

ISBN 978-0-7844-1058-5

1. Water-pipes. 2. Underground pipelines. 3. Pipe, Steel. 4. Flexible couplings. I. Whidden, William R. II. American Society of Civil Engineers. Task Committee on Buried Flexible (Steel) Pipe Load Stability Criteria & Design.

TD491.B865 2009

628.1′5—dc22

2009025043

Published by American Society of Civil Engineers
1801 Alexander Bell Drive
Reston, Virginia 20191

www.pubs.asce.org

ISBN 978-0-7844-1058-5
Manufactured in the United States of America.

16 15 14 13 12 11 10 09 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)

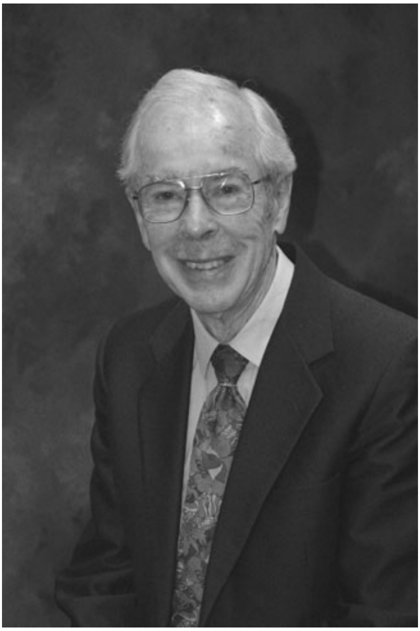
A manual or report in this series consists of an orderly presentation of facts on a particular subject, supplemented by an analysis of limitations and applications of these facts. It contains information useful to the average engineer in his or her everyday work, rather than findings that may be useful only occasionally or rarely. It is not in any sense a "standard," however; nor is it so elementary or so conclusive as to provide 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 work shows the names of the committees by which it was compiled and indicates clearly the several processes through which it has passed in review, in order that its merit may be definitely understood.

In February 1962 (and revised in April 1982) the Board of Direction voted to establish a series entitled "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 reports of joint committees, bypassing of Journal publications may be authorized.

MANUALS AND REPORTS ON ENGINEERING PRACTICE CURRENTLY AVAILABLE

No.	Title
40	Ground Water Management
45	Consulting Engineering: A Guide for the Engagement of Engineering Services
49	Urban Planning Guide
50	Planning and Design Guidelines for Small Craft Harbors
54	Sedimentation Engineering
57	Management, Operation and Maintenance of Irrigation and Drainage Systems
60	Gravity Sanitary Sewer Design and Construction, Second Edition
62	Existing Sewer Evaluation and Rehabilitation
66	Structural Plastics Selection Manual
67	Wind Tunnel Studies of Buildings and Structures
68	Aeration: A Wastewater Treatment Process
71	Agricultural Salinity Assessment and Management
73	Quality in the Constructed Project: A Guide for Owners, Designers, and Constructors
77	Design and Construction of Urban Stormwater Management Systems
80	Ship Channel Design
81	Guidelines for Cloud Seeding to Augment Precipitation
82	Odor Control in Wastewater Treatment Plants
84	Mechanical Connections in Wood Structures
85	Quality of Ground Water
91	Design of Guyed Electrical Transmission Structures
92	Manhole Inspection and Rehabilitation, Second Edition
93	Crane Safety on Construction Sites
94	Inland Navigation: Locks, Dams, and Channels
95	Urban Subsurface Drainage
97	Hydraulic Modeling: Concepts and Practice
98	Conveyance of Residuals from Water and Wastewater Treatment
100	Groundwater Contamination by Organic Pollutants: Analysis and Remediation
101	Underwater Investigations
103	Guide to Hiring and Retaining Great Civil Engineers
104	Recommended Practice for Fiber-Reinforced Polymer Products for Overhead Utility Line Structures
105	Animal Waste Containment in Lagoons
106	Horizontal Auger Boring Projects
107	Ship Channel Design and Operation
108	Pipeline Design for Installation by Horizontal Directional Drilling
109	Biological Nutrient Removal (BNR) Operation in Wastewater Treatment Plants
110	Sedimentation Engineering: Processes, Measurements, Modeling, and Practice
111	Reliability-Based Design of Utility Pole Structures
112	Pipe Bursting Projects
113	Substation Structure Design Guide
114	Performance-Based Design of Structural Steel for Fire Conditions
115	Pipe Ramming Projects
116	Navigation Engineering Practice and Ethical Standards
117	Inspecting Pipeline Inatallation
118	Belowground Pipeline Networks for Utility Cables
119	Buried Flexible Steel Pipe: Design and Structural Analysis



We dedicate this manual of practice to

Dr. Reynold King Watkins, our beloved mentor.

This book would not have been possible without your tireless efforts.

With our warmest gratitude and appreciation, we thank you.

William R. Whidden, P.E., *Chair*
Brent Keil, P.E., *Vice Chair*
Robert J. Card, P.E., *Secretary*
Spyros A. Karamanos, Ph.D.
Randall C. Hill, P.E.
J. Edward Barnhurst, P.E.
David L. McPherson, P.E.
Stephen F. Shumaker, P.E.
Bruce VanderPloeg
Henry H. Bardakjian, P.E.
John L. Luka, P.E.
George F. Ruchti

This page intentionally left blank

PREFACE

Most Americans take for granted that every time they open the faucet, clean, clear water flows out. There is never any thought to the reality that the piping systems used to transport the water is vitally important. But when service is interrupted, then the importance of buried pipe systems to the community becomes a reality and a priority. Without a reliable buried pipe system, an entire community can be momentarily incapacitated.

The purpose of this manual is to provide information on the structural design and analysis of buried steel water and wastewater pipe consistent with the latest pipe and soil design concepts of the industry. Structural design of welded steel pipe ensures adequate performance for the service life of the pipe. Design must be based on required lifetime performance and on limits of performance, sometimes referred to as "failure." This manual also covers the performance limits, which are based on principles of pipe mechanics and soil mechanics, and on the analysis of pipe–soil interaction. This manual, however, does not describe manufacturing procedures, which are satisfactorily addressed by standards from the American Water Works Association and other standards-setting organizations.

An understanding of the principles included in this manual is essential before applying the individual concepts to a design. Otherwise, extracting single design excerpts without that understanding may lead to an erroneous evaluation.

In 1958, Spangler and Watkins published the Modified Iowa Formula for predicting the ring deflection of buried flexible pipe. Flexible pipe deflects under soil load. Ring deflection is a function of stiffness of the ring and support of the ring by soil at the sides of the pipe. The term E' was first promulgated in the Modified Iowa Formula as a measure of that horizontal passive soil support at the sides of the flexible pipe influenced by a size factor. With adequate *E′* values, predicted ring deflection is "controlled" within allowable limits. Unfortunately, *E′* has been used as the basis for design of the pipe rather than the soil, from the inception of the formula up to the present day. This use of *E′* is improper. *E′* was never intended as a means for pipe design. It was originally intended to be a method of predicting the ring deflection that could be verified by field measurement. Furthermore, there is no procedure for testing soil to determine the value of this original *E′*. For the purpose of this manual, the use of the term *E′* refers to the secant modulus of the soil, not to the *E′* of the Modified Iowa Formula.

This manual provides appropriate analytical concepts to address the external loading principles of steel pipe design. Since the 1950s, Dr. Reynold King Watkins of Utah State University—and others—developed these external loading design concepts.

Also, there has long been confusion as to the definition of flexible pipe. Terms such as *flexible, semiflexible, semirigid,* and *rigid* have been used and only add to this confusion. In effect, there are just two basic philosophies of pipe design: flexible and rigid. What differentiates the two design principles is the method of analyzing resistance to internal and external forces.

For rigid pipe design, these forces are additive. A combination internal and external loading analysis is required, in which the stress in the pipe wall created by both thrust and bending forces is evaluated. The structural design of the pipe wall is developed to resist these forces.

In flexible steel pipe design, internal and external pressures are analyzed independently. Any combination analysis would show a reduction of the stress to be resisted. Therefore, independent analyses develop a more conservative design for flexible pipe than would a combined stress analysis. Flexible pipe deflects and conforms with soil embedment as soil is compressed.

When designing steel pipe, the designer must consider issues beyond the thickness of the steel cylinder. These considerations include the type of coating and linings to be applied and the type of joint configuration consistent with the application. Certain coatings and linings are appropriate for some installation conditions and inappropriate for others. The same holds true for the various joint configurations.

As with any design, the designer should always be aware of the nature of the input data and the impact the results of a calculation have on the economics of a project. Rules of thumb do not have to be considered as absolute values. The designer should use discretion when evaluating requirements for project design. Performance limits are not synonymous with failures. Both performance limits and failure mechanisms must be recognized.

Pipes are an efficient and economical means of transporting anything that can flow—fluid, slurry, gas, wire conduits, pedestrians, traffic, and so on. Pipes even provide storage.

The first step for transportation of fluids in pipe is to determine:

- What is to be transported?
- What is the rate (quantity) of flow?
- What are the pressure and pressure variations?

Basic fundamentals of design are pipe design, soil design, and pipe–soil interaction.

This Manual of Practice, *Buried Flexible Steel Pipe: Design and Structural Analysis*, has been organized to provide a structured, chronological design or analysis process for the student or design professional. Here is an overview of each chapter and appendix.

Chapter 1 provides the historical sequence of events leading to our understanding of relationships between buried steel pipe and soil. Chapter 2 lists the notations as used in the manual. Chapter 3 establishes the basis for design of the pipe, not the piping system. This is an important concept in understanding buried steel pipe design. Essentially, the steel pipe resists the internal forces, and the soil support resists the external forces. This chapter provides the design criteria and parameters to analyze pipe stresses and strains as well as explaining limitations on those strains for pipe lining or coating issues.

Chapter 4 provides the geotechnical principles that relate to buried pipe design and analysis. The project's geotechnical report should address certain data to assist the design engineer in analyzing and designing the soil embedment. Significant parameters include the soil unit weight, soil compressibility, and strength at soil slip. Chapter 5 begins the process of analyzing the relationship between pipe and soil that leads to a successful design, which is detailed in Chapter 6. Chapter 6 contains several design examples that demonstrate the design process outlined in the previous chapters. Chapter 7 addresses additional design and analysis topics. These may be uncommon to the majority of buried pipeline installations, such as seismic loading or pipe on supports, or they may be supplemental to a complete design, such as longitudinal thrust forces. There is also information on optional methods of obtaining passive side support, such as flowable fill.

Appendix A is about the Iowa Formula. The Iowa Formula was originally intended to show that ring deflection is primarily a function of soil embedment and was not intended for the design of pipe. This formula has been misused for design for many years. This appendix explains the proper application of the formula.