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Buried Flexible Steel Pipe

Design and Structural Analysis

ASCE

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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

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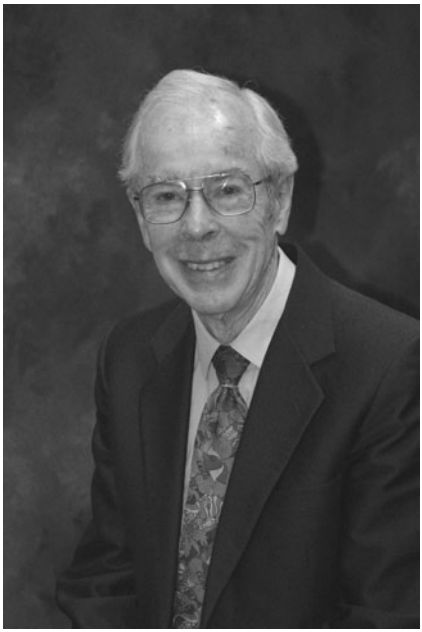
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We dedicate this manual of practice to

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.

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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.

Appendix B is about soil slip analysis. "Soil slip" is the common description of a shearing failure in soil. By analyzing an infinitesimal soil cube using a Mohr stress circle, we can determine or establish soil stability.

In Appendix C, an example is presented to provide the engineer with a representative finite element model. The parallel trench condition was selected to provide a guide to understanding the benefits and procedures of this powerful tool.

Appendix D deals with external fluid pressure. Because external fluid pressure may be capable of collapsing a pipeline, this appendix provides information and examples to assist the engineer in recognizing and evaluating this condition and remedying any potential problem.

Appendix E is called "The Story of Buried Steel Pipes and Tanks." Students committed to an area of expertise should understand the background and history of their chosen field. Dr. Watkins, a pioneer in this field, witnessed—and made—history in the area of buried steel pipes and buried tanks, much of which he personally experienced. This appendix is his historical account and provides a fascinating snapshot of that history and why many of the established concepts evolved.

Appendix F demonstrates that nonuniform ring pressure is statically indeterminate. To approximate the condition, both static equilibrium equations and deformation equations are required. Examples of this condition are presented by applying a dummy force or bending moment to the ring.

Appendix G presents the rationale associated with the development of impact factors for live loads.

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CHAPTER 1
HISTORY OF BURIED STEEL PIPE

Long before buried pipelines evolved as a means of improving people's standards of living, the concept of buried pipes existed in nature. Such "structural engineering" was evident in life forms, from the one-gut worm to the complexity of the human body. In the insect world, communities of insects bored intricate underground tunnels and systems. Rodents burrowed underground in buried pipes that served as their habitats.

The history of buried pipes starts with pipes that serve communities.[1] About 2500 BC, the Chinese delivered water through bamboo pipes. In some Mediterranean countries, clay pipes supplied water to villagers at a central well. Ancient buried pipes in Persia, called *ghanats*, were rock-lined tunnels, dug by hand under the mountains, to collect clean water and pipe it as much as 30 miles to parched cities on the plains. The mountain streams flowed into wetland swamps—all contaminated by sewage, livestock, garbage, snakes, and mosquitoes.

1.1 THE ANCIENT WORLD

In ancient Greece, pipelines and tunnels were constructed to transport and distribute water in urban areas (Fig. 1-1). The most renowned public work of water transportation of the era was the Eupalinos aqueduct in the city of Samos, the capital of an island east of the Aegean Sea. Its construction started in 550 BC (during the ruling of Polycrates), by the

[1] For more on the history of buried pipes, refer to Appendix E.