Steel Penstocks

Second Edition



ASCE Manuals and Reports on
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Steel Penstocks

Second Edition

Prepared by
the Task Committee on Steel Penstock Design of
the Pipeline Planning and Design Committee of
the Pipeline Division of
the American Society of Civil Engineers

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PREFACE

This *Manual of Practice for Steel Penstocks* covers the design, manufacture, installation, testing, start-up, and maintenance of steel penstocks, including branches, wyes, associated appurtenances, and tunnel liners. Standards presented in this manual are applicable only to steel penstocks. As used in the manual, a *penstock* is defined as a closed water conduit located between the first free water surface and a hydroelectric power station.

The *Manual of Practice for Steel Penstocks* was first published in 1993. This 2012 edition is an update of that publication. This update was prepared by a special ASCE task committee under the supervision of the ASCE Pipeline Division with assistance from the ASCE Energy Division. The task committee was charged with updating the manual to match current practice, codes, and standards.

In 1985, the Hydropower Committee began work on the *Civil Engineering Guidelines for Planning and Designing Hydroelectric Developments*, commonly referred to as the *Guides*. Upon the work's completion, the committee decided to expand the section on penstocks into a nationally accepted standard or code.

The penstock design documents most commonly used by the penstock industry are the ASME Boiler and Pressure Vessel Code (ASME Code) and the AISI Steel Plate Engineering Data—Volume 4, Buried Steel Penstocks.

The ASME Code has been in existence since 1914 and originally was based on an allowable stress of one-fifth the tensile strength of the steel. An ASME Code section specifically for pressure vessels came out in the mid-1920s. In the 1950s, the stress basis was changed to one-fourth of the tensile strength of the steel. The high-stress alternative rules, based on one-third of the tensile strength of the steel, came out in the 1960s, although the theory and stress basis had been in use for some time before that. Fabrication based on these rules has resulted in high-quality structures. The rules for both divisions of Section VIII of the ASME Code are accepted worldwide and have been applied to many types of structures other than pressure vessels, including penstocks. The alternative rules of Section VIII, Divisions 1 and 2, have been used extensively in preparing this manual.

The development of Volume 4 was based primarily on the 40-plus years of laboratory research and practical hydroelectric experience of the U.S. Bureau of Reclamation. The manual provides more specific penstock design information than the ASME Code but refers to the latter for fabrication and welding.

Although the procedures outlined in this manual are intended to be clear enough for the inexperienced engineer, many of the decisions on methodology of design and safety factors should be discussed and decided with the aid of an experienced design engineer. Avoiding risk requires a knowledge of diameter, pressure, potential consequence, and many other factors. Proper design of penstocks requires a certain amount of experience.

The design procedures presented in this document are recommended by the task committee. However, the committee recognizes that there are other methods and procedures that may be equally valid. This document does not preclude their use, provided the engineer is satisfied with their validity and applicability.

ACKNOWLEDGMENTS

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Special thanks go to Kyle Couture, who as the secretary for the task committee, administered and managed the documents and numerous meetings.

Finally, special gratitude goes to Sandi Seiger at Denver Water for her efforts in handling the word processing and document assembly, including many revisions, and to Bruce Schulte at Denver Water for his work in CAD producing the figures for the manual.

John H. Bambei Jr., P.E.
Chair, Task Committee for Revision of
ASCE Manual for Steel Penstocks

ABBREVIATIONS AND ACRONYMS

°F	degrees Fahrenheit
AC	alternating current
ACI	American Concrete Institute
AISC	American Institute of Steel Construction
AISI	American Iron and Steel Institute
ANSI	American National Standards Institute
API	American Pipeline Institute
ASCE	American Society of Civil Engineers
ASFM	acoustic scintillation flowmeter
ASME	American Society of Mechanical Engineers
ASME BPVC	American Society of Mechanical Engineers Boiler Pressure Vessel Code
ASNT	American Society for Nondestructive Testing
ASTM	formerly known as American Society for Testing and Materials
ATC	Applied Technology Council
AWS	American Welding Society
AWWA	American Water Works Association
BSSC	Building Seismic Safety Council
BSTC	bolted sleeve type coupling
CE	carbon equivalent
CFMP	Civil Features Monitoring Program
CJP	complete joint penetration
CP	cathodic protection
CSE	copper/copper sulfate reference electrode
CVN	Charpy V-notch
CWI	certified welding inspector
DC	direct current
DFT	dry film thickness
ECS	emergency closure systems
EPRI	Electric Power Research Institute
ESW	electroslag welding
FCAW	flux cored arc welding
FEA	finite element analysis
FEMA	Federal Emergency Management Agency
FERC	Federal Energy Regulatory Commission
ft	feet
GMAW	gas metal arc welding
HAZ	heat-affected zone
HDPE	high-density polyethylene

HSLA	high-strength, low alloy
IARC	International Agency for Research on Cancer
IBC	International Building Code
in.	inch
ISG	intake shutoff gate
ISO	International Organization for Standardization
kip	one thousand pounds
kJ	kilojoules
ksi	kips per square inch
kW	kilowatt
lb	pound
LRFD	load resistance factor design
LST	lowest service temperature
MCE_R	maximum considered earthquake risk
min	minimum
min.	minute
mph	miles per hour
MSDS	material safety data sheet
MSE	mechanically stabilized earth
MSS	Manufacturers Standardization Society
MT	magnetic particle examination
NACE	National Association of Corrosion Engineers
NDE	nondestructive examination
NEHRP	National Earthquake Hazards Reduction Program
NIST	National Institute of Standards and Technology
NPS	nominal pipe size
OD	outside diameter
OSHA	Occupational Safety and Health Administration
P.E.	professional engineer
PG&E	Pacific Gas and Electric Company
PQR	procedure qualification record
PRL	power revenue loss
PRV	pressure reducing valve
psi	per square inch
PSV	penstock shutoff valve
PT	liquid penetrant examination
PVQ	pressure vessel quality
PWF	present worth factor
QA/QC	quality assurance/quality control
ROV	remote operated vehicles
R.P.E.	registered professional engineer
RPM	revolutions per minute
RT	radiographic examination

s	second
SAW	submerged arc welding
Se3	equivalent stress
SI	stress intensity
SMAW	shielded metal arc welding
SNL	speed no load
SPFA	Steel Plate Fabricators Association
SSPC	Society for Protective Coatings
TBM	tunnel boring machine
TSV	turbine shutoff valve
UHMW	ultra-high-molecular weight
USBR	U.S. Bureau of Reclamation
UT	ultrasonic examination
UV	ultraviolet
VT	visual examination
WPQ	welder performance qualification
WPS	welding procedure specification

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CHAPTER 1

General



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This section presents an overview of general penstock design and maintenance issues. More detailed descriptions can be found in subsequent sections. The following pages address general design considerations; internal and external pressure design; economic diameter; shutoff systems; prevention of vibration; wind, snow, and ice loading; earthquake loading; and geologic considerations.

1.1 DESIGN CONSIDERATIONS

The design of a safe and cost-effective penstock system requires the consideration of technical, environmental, economic, and constructibility factors. Figure 1-1 shows the flow of considerations that affect the design of a penstock system. Detailed considerations, guidelines, criteria, and design methodology are presented in subsequent sections.

1.1.1 Required Information

It is important for the designer to gather as much information as possible about the installation. Essential information includes (1) owner requirements and (2) site-specific requirements.

1.1.1.1 Owner Requirements The owner's installation preference and requirements must be clearly delineated because these preferences affect the overall approach to the penstock system, including methodology, material selection, and design. Consideration must be given to the following:

1. Preferred material and design type;
2. Plant operation base load, voltage control peaking, or a combination of both; also important is the likely number of unit operating cycles (i.e., daily start–stop and load change requirement);