

Practical Guide to
GROUTING
of Underground Structures

Raymond W. Henn

ASCE
PRESS

This is a preview. [Click here to purchase the full publication.](#)

PRACTICAL GUIDE TO GROUTING OF UNDERGROUND STRUCTURES

Raymond W. Henn

ASCE
PRESS

Library of Congress Cataloging-in-Publication Data

Henn, Raymond W.

Practical guide to grouting of underground structures / by Raymond W. Henn

p. cm.

ISBN 978-0-7844-1132-2

1. Underground construction. 2. Grouting. I. Title.

TA712.H46 1996

96-3135

624.1'9—dc20

CIP

Published by American Society of Civil Engineers

1801 Alexander Bell Drive

Reston, Virginia 20191

www.pubs.asce.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. This information should not be used without first securing competent advice with respect to its suitability for any general or specific application. Anyone utilizing this 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 U.S. Patent and Trademark Office.

Photocopies and reprints. You can obtain instant permission to photocopy ASCE publications by using ASCE's online permission service (<http://pubs.asce.org/permissions/requests/>). Requests for 100 copies or more should be submitted to the Reprints Department, Publications Division, ASCE (address above); e-mail: permissions@asce.org. A reprint order form can be found at <http://pubs.asce.org/support/reprints/>.

Copyright © 1996 by the American Society of Civil Engineers.

All Rights Reserved.

ISBN 978-0-7844-1132-2

Manufactured in the United States of America.

CONTENTS

Preface vii

1. Introduction 1

 Purpose 3

 Scope 3

2. Grouting Methods 5

 2.1 Grouting in Soil 6

 2.1.1 Jet Grouting 6

 2.1.2 Compaction Grouting 11

 2.1.3 Permeation Grouting 17

 2.1.4 Hydrofracture Grouting 21

 2.2 Grouting in Rock 22

 2.2.1 Consolidation Grouting 23

 2.2.2 Curtain Grouting 23

 2.3 Structural Grouting 24

 2.3.1 Contact Grouting 24

 2.3.1.1 Cast-in-Place Concrete Lining 26

 2.3.1.2 Mapping Cracks in Concrete Lining 30

 2.3.1.3 Precast Concrete Lining 32

 2.3.1.4 Steel and Cast Iron Segment Linings 36

 2.3.1.5 Steel Penstock Lining 38

 2.3.1.6 Tunnel and Station Linings Using
 Waterproofing Systems 39

 2.3.2 Embedment Grouting 43

 2.3.3 Prestressing 44

 2.3.4 Cellular Concrete 49

 2.4 Shaft Grouting 52

 2.4.1 Pregroutings of Shaft from Ground Surface 53

 2.4.2 In-Shaft Grouting 56

 2.5 Probing and Grouting ahead of Tunnel and
 Chamber Excavations 60

 2.5.1 Probe Holes 60

 2.5.2 Grouting ahead of Excavations 61

3. Geotechnical Considerations in Grouting

Program Planning 65

 3.1 Basic Considerations 66

3.2 Geotechnical Investigation and Geotechnical Design Summary	66
3.3 Grouting to Limit Groundwater Infiltration	70
3.4 Grouting to Increase Stability	75
3.5 Grouting to Increase Strength	80
3.6 Groutability Ratio	80
3.7 Other Geotechnical Considerations	81
4. Equipment	83
4.1 Drills	84
4.1.1 Percussion Drilling	86
4.1.2 Rotary Drilling	90
4.1.3 Down-Hole-Drill (Down-Hole-Hammer) Drilling	92
4.2 Mixers	93
4.3 Agitators	98
4.4 Water Meters	100
4.5 Pumps	101
4.6 Pressure Gauges	103
4.7 Gauge Savers	103
4.8 Packers	104
4.9 Nipples	107
4.10 Delivery and Distribution System	109
4.11 Data Acquisition and Recording Equipment	110
4.12 Automated Batching Systems	113
4.13 Grouting Jumbos	117
4.14 Equipment Configuration	117
5. Grouting Materials	121
5.1 Portland Cement	121
5.2 Ultrafine Cement	123
5.3 Sand	124
5.4 Admixtures	124
5.4.1 Dispersants	126
5.4.2 Accelerators	126
5.4.3 Gas-Producing Agents	127
5.5 Water	127
5.6 Bentonite	128
6. Specifications	129
6.1 Applicable ASTM's and Other Standards	130
6.2 Developing Grouting Specifications	130

7. Grout Hole Layout	133
7.1 Grout Hole and Grout Ring Spacing	133
7.1.1 Contact Grouting	133
7.1.2 Consolidation Grouting	140
7.1.3 Curtain Grouting	142
7.2 Hole Depth and Diameter	145
8. Grout Placement Operations	147
8.1 Proportioning	147
8.1.1 Water:Cement Ratios	147
8.1.2 Sand	148
8.1.3 Admixtures	149
8.1.4 Bentonite	149
8.2 Delivery Pressure	149
8.3 Refusal Criteria	155
8.4 Crew Size and Organization	155
8.5 Production	155
8.6 Safety and Environmental Issues	157
8.6.1 Personnel Safety	157
8.6.2 Waste Disposal	159
9. Field Quality Control	161
9.1 Preconstruction Checklists	162
9.2 Certifications and Test Reports	162
9.3 Inspection Reports	162
9.3.1 Drilling Reports	164
9.3.2 Grouting Reports	164
9.4 Testing	164
9.4.1 Laboratory Testing	164
9.4.2 Field Testing	167
10. Chemical Grouting	169
10.1 Applications	169
10.2 Types of Chemical Grouts	170
10.3 Equipment	171
10.3.1 Batching Equipment	171
10.3.2 Injection Equipment	172
10.4 Design of a Chemical Grouting Program	174
10.4.1 Groutability of the Ground	174

10.4.2 Grouting Program Design 175

10.5 Chemical Grouting Case Histories 176

10.5.1 Chemical Grouting from the Surface 176

10.5.2 Chemical Grouting from the Tunnel
Working Face 179

References 183

Index 187

PREFACE

Grouting is a part of most underground civil engineering and mining projects. Depending on the type and operating parameters of the underground facility, geology, and groundwater conditions, grouting can represent a sizable cost and scheduling component of a project. This book is written as a practical guide for engineers, construction supervisors, inspectors, and others involved in the planning, design, and implementation of underground grouting programs. Its primary purpose is to present a hands-on discussion of grouting fundamentals and to provide a foundation for the development of practical specifications and field procedures for underground grouting applications. The reader is encouraged to combine the information in this book with other information sources on grouting. An excellent companion book to this one is *Dam Foundation Grouting*, by Ken Weaver, published in 1991 by the American Society of Civil Engineers.

Cementitious grouting used in conjunction with the excavation and lining of tunnels, shafts, and underground caverns in rock is the primary focus of this work. Overviews of cementitious grouting in soils and chemical grouting are also provided.

The guide takes a practical approach to the subject of underground grouting by concentrating on areas such as grouting methods; types of drilling, mixing, and pumping equipment; and their application. Grouting materials and specifications, record keeping, quality control and testing requirements, field operations, and production rates are also covered. These are all important elements to the overall success of a grouting program, yet they are usually not addressed in detail in engineering literature on grouting.

The guide is intended to compliment existing engineering literature by presenting grouting equipment, technology, and methodologies that are presently available. This information will enhance the planning, field implementation, and quality of an underground grouting program. A better understanding of the capabilities and limitations of the art and science of grouting can only improve the overall results and performance of a grouting program. The text is written assuming that the reader has a basic knowledge of geology, engineering principles, and underground construction methods.

Chapter 3, "Geotechnical Considerations in Grouting Program Planning," was contributed by Thomas M. Saczynski. Chapter 10, "Chemical Grouting," was contributed by Daniel F. McMaster and Michael J. Robison. The computer-generated graphics were created by Vladimir Goubanov. Much of the photographic work was done by Thomas Jenkins. The author would like to thank Pamela Moran, Patricia Henn, and Joe Sperry for their review of the draft manuscript.

CHAPTER 1

INTRODUCTION

The development of cementitious permeation grouting got its start as a method to improve the foundation material of civil engineering structures built in and around bodies of water. The concept of injecting self-hardening cementitious slurry was first employed in 1802 in France to improve the bearing capacity under a sluice (Bruce 1995). The development of cement grouting continued in France and England throughout the 1800s. The applications were concentrated on civil structures such as canals, locks, docks, and bridges (Bruce 1995).

The first recorded use of cementitious grout in underground construction was when, in 1864, Peter Barlow patented a cylindrical one-piece tunnel shield with a cast iron liner constructed from within. The annular void left by the tail of the shield was filled with grout (Tirolo 1994). In 1893 the first systematic grouting of rock in the United States was performed at the New Croton Dam, in New York (Weaver 1991). The grouting program at the Hoover Dam between 1932 and 1935 is said to mark the beginning of systematic design of grouting programs in the United States (Glossop 1961).

The development and advances of underground grouting technology in soil and rock as they apply to design, equipment, and materials have for the most part paralleled the advances made in dam and foundation grouting performed from the surface. Today, most underground civil engineering and mining projects require some form of grouting. Depending on the type and operating parameters of the underground facility, the geology, and ground-water conditions, a grouting program can represent a considerable cost and scheduling component of a project.

Grouting performed in conjunction with engineered underground structures, such as tunnels, shafts, chambers, and mine workings, is similar to grouting operations performed from the surface, such as installing a grout curtain for a dam. In both cases grouting is used to fill pores, fissures, or voids in the host geologic materials to reduce seepage, to strengthen foundation material, or to improve ground-structure interaction.