



PRACTICAL HANDBOOK OF GROUTING

Soil, Rock, and Structures

James Warner, P.E.



WILEY

John Wiley & Sons, Inc.

Contents

<i>Preface</i>	xiii
<i>Acknowledgments</i>	xv
<i>Contributors Biographies</i>	xvii

PART I	THE PRESSURE GROUTING PROCESS	1
Chapter 1	Introduction	3
1.1	History of Grouting	4
1.2	Why Grout?	8
Chapter 2	Types of Grouting	15
2.1	Permeation Grouting	16
2.2	Compaction Grouting	19
2.3	Fracture/Claquage Grouting	31
2.4	Mixing/Jet Grouting	33
2.5	Fill Grouting	37
2.6	Vacuum Grouting	38
Chapter 3	The Wide World of Grout Materials	40
3.1	Cementitious Materials	40
3.2	Admixtures for Cementitious Grouts	42
3.3	Noncementitious Grouts	42
3.4	Material Selection	43
3.5	Basic Material Properties	45
Chapter 4	Grout Rheology	50
4.1	Grout Consistency	51
4.2	Material Behavior	51
4.3	Other Rheological Properties	59

Chapter 5	Cementitious Grout Materials	62
5.1	Portland Cement	62
5.2	Special Cements	70
5.3	Supplementary Cementing Materials	72
5.4	Blended Hydraulic Cements	75
5.5	Ultrafine Cement	76
5.6	Admixtures for Cementitious Grouts	80
5.7	Fillers	87
5.8	Blocking Agents	89
Chapter 6	Cementitious Grout Mixtures	93
6.1	Bleed Water	93
6.2	Water-to-Cement Ratio	95
6.3	Mix Design	96
Chapter 7	Noncementitious Grouts	115
7.1	Chemical Solution Grouts	115
7.2	Chemical Solution Grouts for Strengthening	117
7.3	Chemical Solution Grouts for Water Control	128
7.4	Resinous Grouts	135
7.5	Miscellaneous Grout Materials	141
Chapter 8	Tests for Evaluation of Grouts and Grouted Masses	144
8.1	Flow Cones	144
8.2	Specific Gravity	146
8.3	Evaluation of Bleed	146
8.4	Pressure Filtration	147
8.5	Slump	148
8.6	Strength Tests	149
Chapter 9	Injection Fundamentals	156
9.1	Principles of Flow	156
9.2	Effects of Grout Rheology	163
9.3	Grout Penetration	165
9.4	Injection Pressure	166
9.5	Pumping Rate	170
9.6	Pressure Behavior	171
9.7	Vacuum	177

Chapter 10	Grout Holes	179
10.1	Establishing the Holes	179
10.2	Hole Drilling	186
10.3	Hole Closure and Abandonment	205
Chapter 11	Grouting in Soil	207
11.1	Compaction Grouting	209
11.2	Permeation Grouting in Soil	260
11.3	Fracture (Clauquage) Grouting	286
11.4	Jet Grouting (Mixing)	290
Chapter 12	Grouting in Rock	296
12.1	Know the Rock Properties	297
12.2	Grouting for Water Control	298
12.3	Grouting Rock for Strengthening	309
12.4	Grout Holes	310
12.5	The Grout Mix	317
12.6	Injection Considerations	319
Chapter 13	Grouting in Concrete and Masonry Structures	329
13.1	Filling Structural Cavities and Voids	330
13.2	Filling Cracks and Joints	336
13.3	Contact Grouting	345
13.4	Posttension Tendon Grouting	345
13.5	Grouting Bedplates	349
13.6	Abandoning Conduits and Tanks	352
13.7	Filling Annular Space/Backfilling	354
13.8	Filling Fabric Forms	354
13.9	Preplaced Aggregate Concrete	355
13.10	An Unusual Structural Application	363
Chapter 14	Groutjacking	367
14.1	Slabjacking	367
14.2	Groutjacking Structures	379
Chapter 15	Grouting in Pipes and Conduits	387
15.1	Access Restrictions	387
15.2	Safety Issues	388

15.3	Small Inaccessible Conduits	389
15.4	Worker-Accessible Conduits	392
Chapter 16	Grouting of Underground Structures (Raymond w. Henn)	398
16.1	Geotechnical and Structural Grouting	399
16.2	Excavation Methods	403
16.3	Lining Systems	406
16.4	Conclusions	406
Chapter 17	Leakage Control in Structures	410
17.1	The Leakage Path	410
17.2	Grout Holes/Injection Ports	414
17.3	The Grout Material	417
17.4	Grout Injection and Monitoring	419
17.5	Examples of Use	421
Chapter 18	Grouting in Extreme Environments	427
18.1	Temperature Effects on Grout	427
18.2	Extreme Chemical Exposures	428
18.3	Provisions for Temperature Extremes	429
Chapter 19	The Use of Explosives in Grouting	436
19.1	Introduction	436
19.2	Principles of Explosives Use	438
19.3	Formation of Expanded Head Piles and Ground Anchors	440
19.4	Clearing Obstructions to Grout Flow	444
19.5	Accessing Subsurface Fissures and Voids	445
19.6	In-Place Perforation of Injection Casing	448
19.7	In Conclusion	450
Chapter 20	Emergency Response Grouting	451
20.1	Before Injection Starts	451
20.2	Typical Emergency Situations	453
PART II	GROUTING DESIGN AND CONTROL OF GROUTING	463
Chapter 21	Understanding Geology	465
21.1	Geologic Age	466

21.2	Types of Rock	467
21.3	Geologic Structure	469
21.4	The Rock Configuration/Geometry	474
21.5	Stress State	475
21.6	Derivation of Soil	476
21.7	Classification of Soil	479
21.8	Geotechnical Considerations	483
Chapter 22	Investigations for Grouting	484
22.1	Preliminary Considerations	484
22.2	Soil Grouting	491
22.3	Rock Grouting	495
22.4	Grouting in Structures	496
Chapter 23	Design of Grouting in Soil (Michael J. Byle)	497
23.1	Introduction	497
23.2	Grout Functions in Soil	498
23.3	Mass Improvement	499
23.4	Modulus/Strength Improvement	501
23.5	Permeability Reduction	505
23.6	Structural Elements	505
23.7	Karst Mitigation	508
23.8	Design Summary	510
Chapter 24	Design of Grouting in Rock	511
24.1	The Existing Geology	512
24.2	Strengthening Applications	514
24.3	Seepage Control	516
Chapter 25	Quality Control, Records, and Verification	519
25.1	Quality Control	519
25.2	Injection Records	524
25.3	Verification of Grouting Effectiveness	529
Chapter 26	Numerical Analysis of Grouting (Dawn Shuttle and Mike Jefferies)	531
26.1	About Numerical Analysis	531
26.2	Fractured Rock Grouting	532
26.3	Compaction Grouting	538

Chapter 27	Specifications and Contracts	543
27.1	Specification Requirements	544
27.2	Contracting Arrangements	559
27.3	Full-Scale Trials	563
Chapter 28	The Games Contractors Play	564
28.1	Marketing Efforts	565
28.2	Proposal Trickery	568
28.3	Once on the Job	568
28.4	Defending Bad Work	569
28.5	The Good Players	570

PART III DRILLING AND GROUTING EQUIPMENT **573**

Chapter 29	Understanding Power Transmission	575
29.1	Power Transmission Fundamentals	575
29.2	Mechanical Systems	577
29.3	Hydraulic Systems	582
29.4	Pneumatic Systems	587
Chapter 30	Drilling Equipment and Accessories	589
30.1	Drill Rigs	589
30.2	Drill Hole Casing	597
30.3	Drill Rod	605
30.4	Drill Bits	610
30.5	Sleeve Port Pipes (Tube-à-Manchette)	613
30.6	Special Drive Needles	614
30.7	Circulation (Mud) Pumps	614
Chapter 31	Pump Mechanics	615
31.1	Pumping Fundamentals	615
31.2	Classification of Pumps	616
31.3	Types of Pumps	617
Chapter 32	Grout Pumps	627
32.1	Power Source	627
32.2	Types of Grout Pumps	628
Chapter 33	Batchers, Mixers, and Agitators	635
33.1	Small Mixers	635
33.2	Mixing Equipment for Pourable Grouts	637

33.3	Agitators	641
33.4	Material Storage and Transfer Equipment	641
33.5	Equipment for Low-Mobility Grouts	643
Chapter 34	Unitized Grout Plants	646
34.1	Basic Considerations	646
34.2	Plants for Pourable Cementitious Grouts	647
34.3	Grout Plants for Low-Mobility Grouts	652
34.4	Custom-Built Grout Plants	652
Chapter 35	Delivery Lines and Fittings	654
35.1	Delivery Lines	654
35.2	Valves	661
Chapter 36	Monitoring Equipment	663
36.1	Pressure Gauges	663
36.2	Gauge Savers	665
36.3	Flow Meters	668
36.4	Automated Monitoring Equipment	669
Chapter 37	Packers	672
37.1	Types of Packers	672
37.2	Packer Deployment	675
37.3	Double Packers	677
Chapter 38	Some Closing Thoughts	678
	<i>Bibliography and References</i>	685
	<i>Index</i>	691