

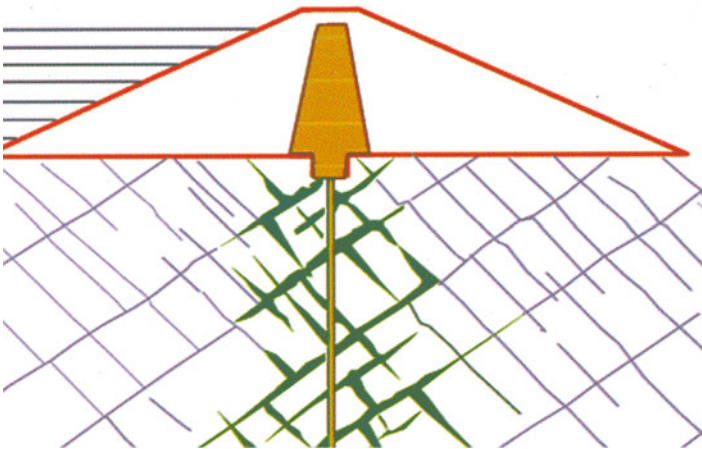
Professional Practice in Earth Sciences

Series editor

James W. LaMoreaux, Tuscaloosa, AL, USA

More information about this series at <http://www.springer.com/series/11926>

Rock Grouting at Dam Sites



Friedrich-Karl Ewert · Ulrich Hungsberg

Rock Grouting at Dam Sites

 Springer

Friedrich-Karl Ewert
University of Paderborn
Paderborn
Germany

Ulrich Hungsberg
Department of Consulting
Comision Nacional del Agua
Mexico
Mexico

ISSN 2364-0073 ISSN 2364-0081 (electronic)
Professional Practice in Earth Sciences
ISBN 978-3-319-64035-8 ISBN 978-3-319-64036-5 (eBook)
DOI 10.1007/978-3-319-64036-5

Library of Congress Control Number: 2017946961

© Springer International Publishing AG 2018

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Task

Grouting is the usual method to seal a permeable dam foundation. In spite of alternative technologies—diaphragm walls, for instance—many sites will remain whose conditions still favour conventional grouting. Dam foundation grouting today is mostly rock grouting. The decision to grout is usually based on the results of water pressure tests (WPT), and it is assumed that the permeability can be reduced by means of grouting to the desired degree. The possibility to press grout suspension into the rock was supposed to confirm both the need and the success of a grouting program. This concept resulted in many inconsistencies. It is prudent to establish a new one: WPT-results should not be the only basis for the decision to grout, the hydrogeological setting of the whole foundation should be also considered. Rock types are not equally groutable but have individual groutabilities which only permit a specific reduction of their permeability. Grouting pressures should not be related to depth but to both the individual geological setting and the purpose of a grouting program.

Contents

1	Introduction	1
2	Water Flow in Rock: Geometry of Water Conducting Paths and Lugeon-Values	5
3	Examples of Grouting Programs	11
3.1	Tavera Dam	11
3.2	Antrift, Haune and Twiste Dams	14
3.3	Möhne Dam	23
3.4	Prims Dam	25
3.5	Almendra Dam	27
3.6	Aabach Dam	30
3.7	Yuracmayo Dam	35
3.8	Grouting in Karstic Limestone	37
3.8.1	Introduction	37
3.8.2	Pueblo Viejo Dam/Guatemala	38
3.8.3	Panix Dam/Switzerland	46
3.8.4	Mujib Dam	52
3.8.5	Conclusions for Dam Sites in Karstic Limestone	69
3.9	Conclusions Drawn from These Examples	71
4	Permeability Testing by Means of Water Pressure Tests	75
4.1	Execution	75
4.1.1	Packer	75
4.1.2	Automatic Recording	75
4.1.3	Maximum Test Pressure	76
4.1.4	Increasing and Decreasing Pressure Steps	77
4.2	Evaluation	78
4.2.1	Pressure Correction	78
4.2.2	Graphical Presentation	81
4.2.3	WPT-Values Proposed	83

4.2.4	Computerized Evaluation	84
4.3	Hydrofracturing Caused and Indicated by WPT's	84
4.3.1	Splitting and Dilatation	84
4.3.2	Erosion and Clogging	88
4.4	Classification and Interpretation of P/Q-Diagrams	88
4.5	Size and Shape of Water Paths and Absorption Rates, Ambiguity of WPT's	94
4.6	WPT-Values and Coefficient of Permeability (k_f)	96
4.7	Assessment of the Usefulness of WPT's	97
4.7.1	Permeability	97
4.7.2	Deformability	98
4.8	Typological Classification by Means of WPT's	100
4.8.1	Massive Conglomerate with Intercalated Siltstone Beds	100
4.8.2	Well Bedded Sandstone-Siltstone-Alternations	101
4.8.3	Carboniferous Shale with Intercalated Sandstones	102
4.8.4	Slightly Karstic Limestone	102
4.8.5	Competent Granite	102
4.8.6	Miocene Molasse	103
4.8.7	Well Bedded Quartzite	103
4.8.8	Massive Competent Limestone	104
4.9	Impermeabilization Criteria Based on WPT-Values	106
4.10	Directions of Unequal Permeability	109
5	Hydrofracturing of Latent Discontinuities in Rock and Implications for Successful and Economical Execution of Grouting	111
5.1	Introduction	111
5.2	Problem	112
5.3	Basis of Examination	114
5.4	Classification of P/Q-Diagrams	117
5.5	Factors Ruling Hydrofracturing and Hydrojacking	117
5.6	Data Evaluated	119
5.7	Results	120
5.7.1	Aixola	120
5.7.2	Albarelo	120
5.7.3	Almendra	123
5.7.4	Argoza	124
5.7.5	Arriaran	125
5.7.6	Benamor	126
5.7.7	Burdalo	126
5.7.8	El Canal	127
5.7.9	Cernadilla	128
5.7.10	San Cosmade	129

5.7.11	Doña Ana and Laredo	129
5.7.12	Edrada	130
5.7.13	Santa Eulalia	131
5.7.14	La Llosa Del Caval	132
5.7.15	Mingorria	133
5.7.16	Palancia	133
5.7.17	Ponga	134
5.7.18	Las Portas	135
5.7.19	Riansares	136
5.7.20	Valdejudios	137
5.7.21	Results of WPT's Carried Out in Other Countries.	138
5.7.22	Interpretation	138
5.7.23	Summary	144
5.8	Mechanism of Hydrofracturing Processes	145
5.8.1	Type of Latent Discontinuities Susceptible to Fracturing	145
5.8.2	Angle of Intersection Between Borehole and Susceptible Plane	145
5.8.3	Drilling Technique.	145
5.8.4	Hydraulic Jack.	146
5.8.5	Stress Field at the Entrance of a Susceptible Plane	146
5.8.6	Self-Induced Chain Reaction Due to Stiffness of Rock Bordering the Plane Being Fractured.	146
5.8.7	Development of Pressure During Fracturing and Subsequent Grouting	147
5.9	Results of Grouting Programs Using Conventional Grouting Pressures.	147
5.10	Changes of Absorption Capacity Due to Hydrojacking and Hydrofracturing	150
5.11	Comparison Between Critical Pressures Occurring in WPT's and Grouting.	151
5.12	Hydraulic Fundamentals of Testing and Grouting Processes.	153
5.13	Consequences	154
5.13.1	Hydrofracturing and Individual Groutability	154
5.13.2	Hydrofracturing Restricts Width and Depth of Groutable Paths.	157
5.13.3	Hydrofracturing Restricts Grouting Pressure	160
5.13.4	Hydrofracturing Causes Economical Disadvantages.	161
5.14	Conclusions	162
6	Groutability and Grouting of Rock	165
6.1	General Information	165
6.2	Hydraulic Characteristics of Water Paths	166
6.3	Water/Cement-Ratio	167

6.4	Execution and Grouthole Pattern	169
6.5	Evaluation of Data to Control the Grouting Process	171
6.6	Relationship Between WPT-Values and Grout Takes	176
6.7	Hydrofracturing Caused and Indicated by Grouting	177
6.8	Orientation of Groutstone Layers Intercalated Due to Hydrofracturing	179
6.9	Individual Groutability	179
6.10	Grouting Pressure	182
6.10.1	High Pressure Grouting	182
6.10.2	Concept of the Depth-Dependent Grouting Pressure	184
6.10.3	Influence of Geological Conditions on the Initial Grouting Pressure	185
6.10.4	Influence of Geological Conditions on the Course of the Pressure During Grouting	186
6.10.5	Influence of Rheological Properties of Suspension on Grouting Pressure	188
6.10.6	Grouting Pressure Appropriate for Various Geological Conditions	189
6.11	Test Grouting	193
6.12	Type of Water Paths, Grouthole Pattern and Grout Takes	196
6.13	Final Remarks	196
7	Hydrogeological Regime Around Dams and Reservoirs	199
7.1	Introduction	199
7.2	The Position and Inclination of the Groundwater Table	200
7.2.1	Steep Inclination of the Groundwater Table Indicates Impervious Rock	202
7.2.2	Flat Inclination of the Groundwater Table Indicates Permeable Rock	202
7.3	Seepage and Uplift at the Dam Site	203
7.3.1	Influence of Geological Features Causing an Anistropical Permeability	203
7.3.2	Depth of Curtain; Connected or Hanging Curtain	207
7.3.3	Lateral Extension of the Grout Curtain in Relation to the Length of Flow Lines	208
7.3.4	Inclination of Groundwater Level and Lateral Extension of a Grout Curtain	210
7.4	Water-Tightness of the Reservoir	211
7.4.1	Deep Position of Groundwater Table	211
7.4.2	Impact of the Reservoir on the Groundwater	212
7.4.3	Precautionary Measures	214
7.5	Hydraulic Computations	215

- 8 Doubts in GIN Principle Confirmed** 221
 - 8.1 Introduction 221
 - 8.2 Fundamental Characteristics 222
 - 8.2.1 Grouting Processes: Theoretical Analysis or Empirical Research 222
 - 8.2.2 Hydrojacking and Hydrofracturing 223
 - 8.2.3 Hydrofracturing and Hydrojacking Related to Grouting Intensity 224
 - 8.2.4 GIN and Grouting Pressure in Shallow Zones 225
 - 8.2.5 Optimal Grouting Pressure Related to Depth 226
 - 8.2.6 Optimal Grouting Pressure Related to Future Water Pressure 226
 - 8.3 Critical Components of the GIN Principle 227
 - 8.3.1 Grouting Intensity and GIN Limiting Curve 227
 - 8.3.2 Definition of Grouting Pressure and Volume of Grout 228
 - 8.3.3 Water Pressure Tests and Groutability 229
 - 8.4 Final Remarks 229
 - 8.4.1 The GIN-Principle 230
 - 8.4.2 Concept of ‘Grouting Guided by Facts’ 230
- Bibliography** 233