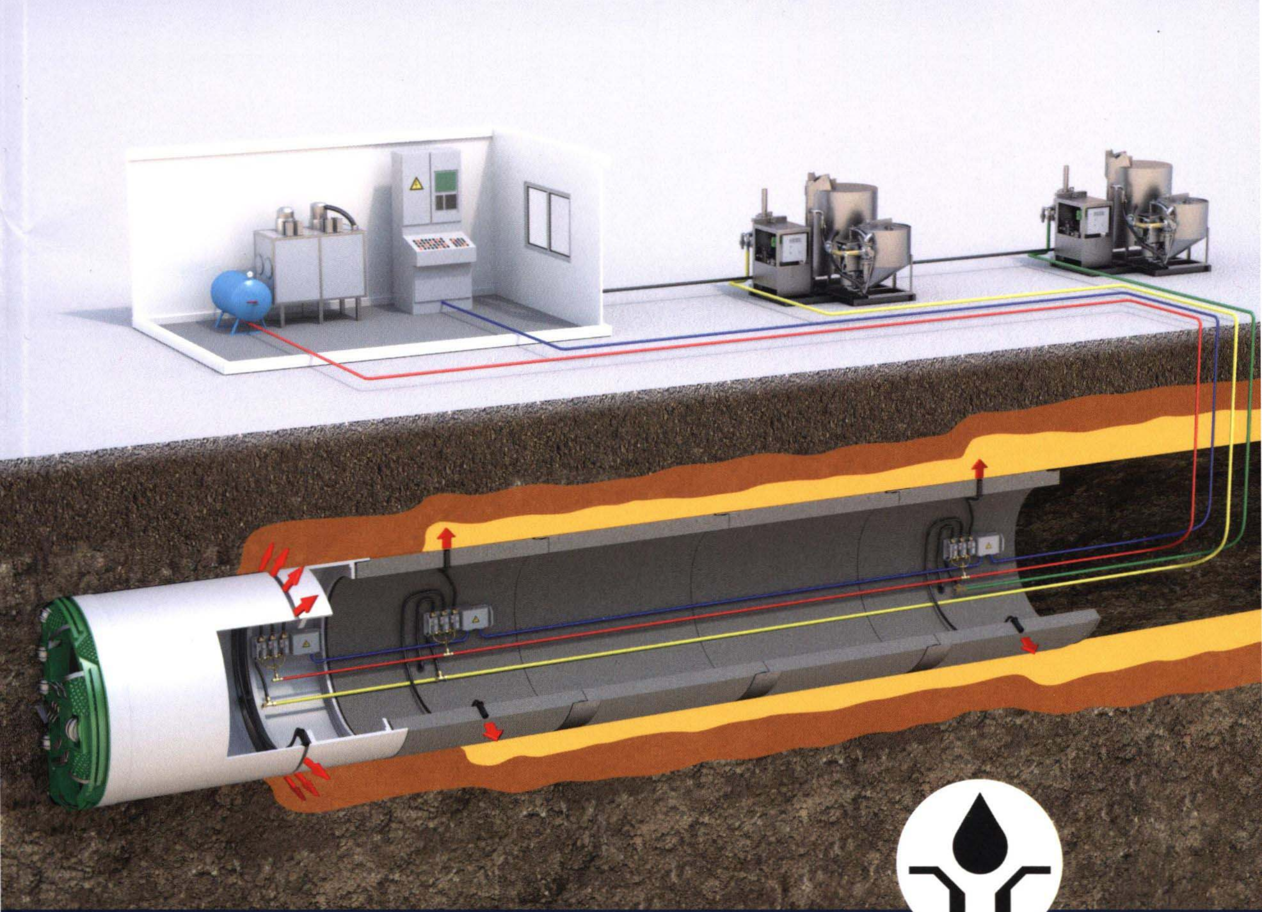

Steffen Praetorius / Britta Schößer

Bentonite Handbook

Lubrication for Pipe Jacking

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Cover: Principle of construction of the standard Herrenknecht bentonite lubrication system (Source: Herrenknecht AG)

Library of Congress Card No.:
applied for

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library.

Bibliographic information published by
the Deutsche Nationalbibliothek
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available on the Internet at <http://dnb.d-nb.de>.

Coverdesign: Sophie Bleifuß, Berlin, Germany
Production management: pp030 – Produktionsbüro Heike Praetor, Berlin
Typesetting: Reemers Publishing Services GmbH, Krefeld
Printing and Binding: CPI books GmbH, Leck

Printed in the Federal Republic of Germany.
Printed on acid-free paper.

Print ISBN: 978-3-433-03137-7
ePDF ISBN: 978-3-433-60655-1
ePub ISBN: 978-3-433-60653-7
eMobi ISBN: 978-3-433-60654-4
oBook ISBN: 978-3-433-60652-0

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For Angela, Lucia and Luana

S.P.

For Holger, Leo and Ole

B.S.

Acknowledgement

Intensive specialist discussion about challenges in pipe jacking practice and scientific findings has found its way into this Bentonite Handbook and sprouted new (research) ideas. For their valuable contributions, we wish to thank the After Sales staff of the Utility Tunnelling department at Herrenknecht AG as well as the experienced and motivated specialists on pipe jacking sites. For their detailed discussions, we wish to thank Ms. Dipl.-Ing. Geotechnik/Bergbau *Christel Flittner,* Mr. Dipl.-Ing. Tiefbohrtechnik *Oliver Knopf,* Ms. *Irmhild Lauter,* Mr. *Ulrich Schröder,* Mr. *Hermann Spengler* and Mr. Dipl.-Geol. *Björn Zenner.*

Mr. Dipl.-Geol. *Matthias Botzenhardt* made a particular contribution with his expert assistance regarding the subject of additives. The production of drawings and text was supported by Mr. Dipl.-Ing. *Nick Biermann,* Ms. *Melanie Ruff,* Mr. *Roman Duda* and Mr. *Tobias Bucher.*

We wholeheartedly thank Mr. Prof. Dr.-Ing. *Markus Thewes* and Mr. Dr.-Ing. *Marc Peters* as well as the research and development colleagues of the Utility Tunnelling department at Herrenknecht AG and at the Chair of Tunnelling and Construction Management at the Ruhr University, Bochum for their sympathetic support and the pleasant working atmosphere. The publisher Ernst & Sohn and particularly Mr. Dr. *Helmut Richter,* Ms. *Esther Schleidweiler,* Mr. Dr. *Michael Bär* and Mr. *David Sturge* deserve our gratitude for their support in the implementation and design of the book.

We would be pleased to receive feedback and suggestions.

Steffen Praetorius and Britta Schößer

Foreword

Pipe jacking is an indispensable process for the installation of underground pipes. Constant improvement of the machinery in recent decades has led to pipe jacking projects being successfully completed in almost any geology and hydrogeology, with challenging routes. The success of a pipe jacking project is ensured by smooth interaction of the tunnelling technology and the process operations. The main challenges, which are met daily on pipe jacking projects, are to minimise potential risks and to increase the practical distances.

The development of the jacking force over the length of the drive – and particularly the skin friction along the pipe string – is of central importance for the implementation of pipe jacking projects. Improved working methods can avoid increased jacking forces and the resulting delays to progress or stoppages. One essential element in the reduction of skin friction is well functioning annular gap lubrication, with the lubricant and the lubrication technology being adapted to suit the constraints of the jack and particularly the ground conditions. Both components – lubricant and lubrication technology – depend on important details and demand a good basic understanding on the part of the construction staff.

The lubricant mostly consists of a bentonite suspension, whose rheological parameters yield point and viscosity have to be adapted to suit the prevailing geological conditions on each pipe jacking project. It has to be correctly prepared and the rheological parameters checked according to standards. The lubrication technology supplies the lubricant continuously in sufficient quantity into the annular gap. In advance, the required quantities of lubricant over the course of the jack have to be determined, prepared in good time and kept available in sufficient volume. These figures depend directly on the size of the tunnelling machine and the jacked pipe as well as the soil mechanics parameters grading distribution, compaction and permeability. When an automatic bentonite lubrication system is used, the number of injection fittings in the pipe section at a lubrication point has to be decided as well as the spacing of the lubrication points and their injection intervals in the tunnelling machine and in the pipe string.

Precise matching of the individual aspects makes it possible to hold the pipe string in the correct position, considerably reduce the coefficient of friction between pipe and ground and finally keep the skin friction controllable as jacking proceeds.

The Bentonite Handbook deals with the various aspects of annular gap lubrication comprehensively, and should serve well as a design aid and a guideline for site practice. It is of course not possible to exhaustively deal with all practical problems of pipe jacking. Responsible action by well trained engineers will always remain the basis of good and successful construction even with the use of this book.

Professor *Markus Thewes*

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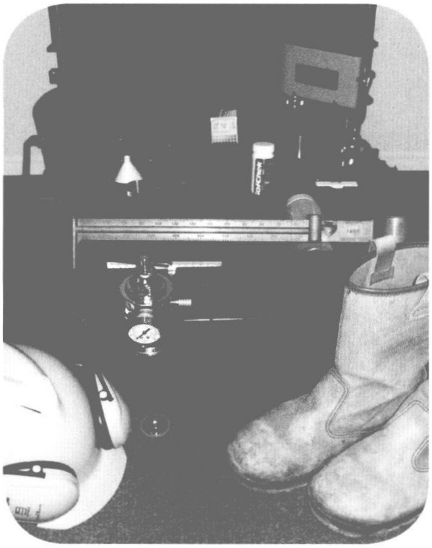

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List of symbols used

I. Greek symbols

γ	specific weight
γ_{concrete}	specific weight of reinforced concrete
$\gamma_{\text{suspension}}$	Specific weight of suspension
$\gamma_{\text{particles}}$	Specific weight of solid particles
η	(dynamic) viscosity
η'	differential viscosity
η_{s}	apparent viscosity
η_{p}	plastic viscosity
λ	Darcy friction factor
μ	coefficient of friction
ρ	density
ρ_{f}	density of suspension
ρ_{s}	density of solid particles
$\rho_{\text{suspension}}$	density of suspension
$\rho_{\text{particles}}$	density of solid particles
σ_{c}	rock strength
τ	shear stress
τ_{B}	Bingham yield point
τ_{F}	yield point
φ	internal angle of friction (shear strength)
φ'	angle of shear resistance (dynamic probing); drained friction angle (shear strength)
φ_{u}	undrained friction angle (shear strength)
χ	adaption parameter from *Slichter* (Eqn. 6.13)

II. Latin symbols

a	half fissure opening width
A	adaption parameter from *von Soos* (Eqn. 6.17)
$A_{\text{pipe string}}$	developed area of the pipe string

B	adaption parameter from *von Soos* (Eqn. 6.17)
c	form coefficient from *Kozeny* (Eqn. 6.14)
c'	drained cohesion (shear strength)
$c_{\text{particles}}$	
c_{u}	undrained cohesion (shear strength)
c_{w}	resistance coefficient
C	proportionality factor from *Hazen* (Eqn. 6.15); adaption parameter from *von Soos* (Eqn. 6.17)
$C_{\text{joint space}}$	joint volume in rock
C_{casing}	supplement factor for the developed area of the pipe for injection into the surrounding ground
C_{porosity}	porosity of soils
d	void spacing
d_{10}	grain diameter at 10% passing (effective diameter)
d_{60}	grain diameter at 60% passing
d_{50}	grain diameter at 50% passing
d_{s}	diameter of solid particles
d_{particle}	diameter of a soil particle
d_{w}	effective grain diameter
D	compaction; velocity gradient
e	void ratio; void opening width
$e_{\max}$	maximum possible void ratio
$e_{\min}$	minimum possible void ratio
f	filtrate water loss
f_{s}	local skin friction (dynamic probing)
F	area; force
F_{A}	uplift force
F_{uplift}	uplift force on the jacked pipe
F_{borehole}	developed area of the excavated section
F_{G}	weight force
F_{weight}	weight force of the jacked pipe

$F_{weight\ installations}$	weight force of installations (cables, pipes etc.) in the jacked pipe
$F_{R,spec}$	specific skin friction
$F_{jacking}$	jacking force of the pipe string
F_{W}	resistance against sinking of a soil particle in the suspension
g	acceleration due to gravity
h	pressure head difference
I_{A}	activity
I_{C}	consistency index
I_{D}	relative density
I_{P}	plasticity index (Atterberg)
J	hydraulic gradient, fall
J_{a}	joint alteration number (RQD)
J_{n}	joint set number (RQD)
J_{r}	joint roughness number (RQD)
J_{w}	reduction factor for groundwater
k_{f}	permeability, coefficient of permeability
k_{k}	fissure permeability (Eqn. 6.18)
k_{s}	sand roughness height
k_{T}	rock permeability with a fissure set
K	coefficient
l	length, distance
$l_{overcut}$	overcut
$L_{reference}$	length of the reference drive
m_{D}	dry mass of grains with a diameter greater than 0.4 mm
m_{T}	dry mass of grains with a diameter less than 0.002 mm
$M_{ballasting}$	mass required to ballast the jacked pipe
n	porosity
n_{e}	usable porosity
n_{max}	maximum possible porosity
n_{min}	minimum possible porosity

N_0	adaptation ramming: number of impacts for the first 15 cm penetration depth (dynamic probing)
N_{10}	number of impacts for 10 cm penetration depth (dynamic probing)
N_{30}	number of impacts for 30 cm penetration depth after the adaptation ramming (dynamic probing)
p	pressure
q_c	tip pressure (dynamic probing)
Q	*Q-value (measure of rock mass quality); flow quantity of a fluid*
$Q_{machine}$	pumping rate at the tunnelling machine
$Q_{pipe\ string}$	pumping rate at the pipe string
Re	Reynolds number
s	penetration depth (of the suspension into the surrounding ground)
t	time; temperature
$t_{10'}$	gel strength after 10 min
$t_{10''}$	gel strength after 10 s
t_M	Marsh time
t_{M1500}	Marsh time for 1500 ml of suspension to run out
w	water content
w_L	water content of a soil at the transition from liquid to plastic consistency (liquid limit)
w_P	water content of a soil at the transition from stiff to semi-solid consistency (plastic limit)
w_S	water content of a soil at the transition from semi-solid to solid consistency (shrinkage limit)
U	coefficient of uniformity
v	flow velocity
v_f	filter rate
$v_{advance}$	advance rate
V	(total) volume
V_H	volume of voids
$V_{machine}$	initial injection volume
$V_{extra\ injection}$	extra suspension volume

$V_{\text{annular gap}}$	annular gap volume
$V_{\text{pipe string}}$	subsequent injection volume
V_{t}	volume of solids
w_{s}	sinking speed