Steffen Praetorius / Britta Schößer

Bentonite Handbook

Lubrication for Pipe Jacking
Steffen Praetorius
Britta Schözser

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Lubrication for Pipe Jacking
Dipl-Geol. Steffen Praetorius  
Herrenknecht AG  
Business Unit Utility Tunnelling  
Schlehenweg 2, D-77963 Schwanau-Allmannsweier

Dr.-Ing. Britta Schößer  
Ruhr-Universität Bochum  
Lehrstuhl für Tunnelbau, Leitungsbau und Baubetrieb  
Universitätsstr. 150, D-44801 Bochum

Translated by David Sturge, Kirchbach, Germany

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For Angela, Lucia and Luana

S.P.

For Holger, Leo and Ole

B.S.
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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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I. Greek symbols

\( \gamma \)  
specific weight

\( \gamma_{\text{concrete}} \)  
specific weight of reinforced concrete

\( \gamma_{\text{suspension}} \)  
Specific weight of suspension

\( \gamma_{\text{particles}} \)  
Specific weight of solid particles

\( \eta \)  
(dynamic) viscosity

\( \eta' \)  
differential viscosity

\( \eta_s \)  
apparent viscosity

\( \eta_p \)  
plastic viscosity

\( \lambda \)  
Darcy friction factor

\( \mu \)  
coefficient of friction

\( \rho \)  
density

\( \rho_f \)  
density of suspension

\( \rho_s \)  
density of solid particles

\( \rho_{\text{suspension}} \)  
density of suspension

\( \rho_{\text{particles}} \)  
density of solid particles

\( \sigma_c \)  
rock strength

\( \tau \)  
shear stress

\( \tau_B \)  
Bingham yield point

\( \tau_F \)  
yield point

\( \varphi \)  
internal angle of friction (shear strength)

\( \varphi' \)  
angle of shear resistance (dynamic probing); 
  drained friction angle (shear strength)

\( \varphi_u \)  
undrained friction angle (shear strength)

\( \chi \)  
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
List of symbols used

$B$  
adaption parameter from von Soos (Eqn. 6.17)

c  
form coefficient from Kozeny (Eqn. 6.14)

c$'$  
drained cohesion (shear strength)

c$_{\text{particles}}$  
undrained cohesion (shear strength)

c$_{u}$  
resistance coefficient

c$_{w}$  
proportionality factor from Hazen (Eqn. 6.15); adaption parameter from von Soos (Eqn. 6.17)

$C_{\text{joint space}}$  
joint volume in rock

$C_{\text{casing}}$  
supplement factor for the developed area of the pipe for injection into the surrounding ground

$C_{\text{porosity}}$  
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$_{\text{particle}}$  
diameter of a soil particle

d$_{w}$  
effective grain diameter

$D$  
compaction; velocity gradient

e  
void ratio; void opening width

e$_{\text{max}}$  
maximum possible void ratio

e$_{\text{min}}$  
minimum possible void ratio

$f$  
filtrete water loss

$f_{s}$  
local skin friction (dynamic probing)

$F$  
area; force

$F_{A}$  
uplift force

$F_{\text{uplift}}$  
uplift force on the jacked pipe

$F_{\text{borehole}}$  
developed area of the excavated section

$F_{G}$  
weight force

$F_{\text{weight}}$  
weight force of the jacked pipe
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( F_{\text{weight installations}} )</td>
<td>weight force of installations (cables, pipes etc.) in the jacked pipe</td>
</tr>
<tr>
<td>( F_{\text{R,spec}} )</td>
<td>specific skin friction</td>
</tr>
<tr>
<td>( F_{\text{jacking}} )</td>
<td>jacking force of the pipe string</td>
</tr>
<tr>
<td>( F_W )</td>
<td>resistance against sinking of a soil particle in the suspension</td>
</tr>
<tr>
<td>( g )</td>
<td>acceleration due to gravity</td>
</tr>
<tr>
<td>( h )</td>
<td>pressure head difference</td>
</tr>
<tr>
<td>( I_A )</td>
<td>activity</td>
</tr>
<tr>
<td>( I_C )</td>
<td>consistency index</td>
</tr>
<tr>
<td>( I_D )</td>
<td>relative density</td>
</tr>
<tr>
<td>( I_P )</td>
<td>plasticity index (Atterberg)</td>
</tr>
<tr>
<td>( J )</td>
<td>hydraulic gradient, fall</td>
</tr>
<tr>
<td>( J_a )</td>
<td>joint alteration number (RQD)</td>
</tr>
<tr>
<td>( J_n )</td>
<td>joint set number (RQD)</td>
</tr>
<tr>
<td>( J_r )</td>
<td>joint roughness number (RQD)</td>
</tr>
<tr>
<td>( J_w )</td>
<td>reduction factor for groundwater</td>
</tr>
<tr>
<td>( k_f )</td>
<td>permeability, coefficient of permeability</td>
</tr>
<tr>
<td>( k_k )</td>
<td>fissure permeability (Eqn. 6.18)</td>
</tr>
<tr>
<td>( k_s )</td>
<td>sand roughness height</td>
</tr>
<tr>
<td>( k_T )</td>
<td>rock permeability with a fissure set</td>
</tr>
<tr>
<td>( K )</td>
<td>coefficient</td>
</tr>
<tr>
<td>( l )</td>
<td>length, distance</td>
</tr>
<tr>
<td>( l_{\text{overcut}} )</td>
<td>overcut</td>
</tr>
<tr>
<td>( L_{\text{reference}} )</td>
<td>length of the reference drive</td>
</tr>
<tr>
<td>( m_D )</td>
<td>dry mass of grains with a diameter greater than 0.4 mm</td>
</tr>
<tr>
<td>( m_T )</td>
<td>dry mass of grains with a diameter less than 0.002 mm</td>
</tr>
<tr>
<td>( M_{\text{ballasting}} )</td>
<td>mass required to ballast the jacked pipe</td>
</tr>
<tr>
<td>( n )</td>
<td>porosity</td>
</tr>
<tr>
<td>( n_e )</td>
<td>usable porosity</td>
</tr>
<tr>
<td>( n_{\text{max}} )</td>
<td>maximum possible porosity</td>
</tr>
<tr>
<td>( n_{\text{min}} )</td>
<td>minimum possible porosity</td>
</tr>
<tr>
<td>Symbol</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
</tr>
<tr>
<td>$N_0$</td>
<td>adaptation ramming: number of impacts for the first 15 cm penetration depth (dynamic probing)</td>
</tr>
<tr>
<td>$N_{10}$</td>
<td>number of impacts for 10 cm penetration depth (dynamic probing)</td>
</tr>
<tr>
<td>$N_{30}$</td>
<td>number of impacts for 30 cm penetration depth after the adaptation ramming (dynamic probing)</td>
</tr>
<tr>
<td>$p$</td>
<td>pressure</td>
</tr>
<tr>
<td>$q_c$</td>
<td>tip pressure (dynamic probing)</td>
</tr>
<tr>
<td>$Q$</td>
<td>$Q$-value (measure of rock mass quality); flow quantity of a fluid</td>
</tr>
<tr>
<td>$Q_{\text{machine}}$</td>
<td>pumping rate at the tunnelling machine</td>
</tr>
<tr>
<td>$Q_{\text{pipe string}}$</td>
<td>pumping rate at the pipe string</td>
</tr>
<tr>
<td>$Re$</td>
<td>Reynolds number</td>
</tr>
<tr>
<td>$s$</td>
<td>penetration depth (of the suspension into the surrounding ground)</td>
</tr>
<tr>
<td>$t$</td>
<td>time; temperature</td>
</tr>
<tr>
<td>$t_{10}'$</td>
<td>gel strength after 10 min</td>
</tr>
<tr>
<td>$t_{10}$</td>
<td>gel strength after 10 s</td>
</tr>
<tr>
<td>$t_M$</td>
<td>Marsh time</td>
</tr>
<tr>
<td>$t_{M1500}$</td>
<td>Marsh time for 1500 ml of suspension to run out</td>
</tr>
<tr>
<td>$w$</td>
<td>water content</td>
</tr>
<tr>
<td>$w_L$</td>
<td>water content of a soil at the transition from liquid to plastic consistency (liquid limit)</td>
</tr>
<tr>
<td>$w_P$</td>
<td>water content of a soil at the transition from stiff to semi-solid consistency (plastic limit)</td>
</tr>
<tr>
<td>$w_S$</td>
<td>water content of a soil at the transition from semi-solid to solid consistency (shrinkage limit)</td>
</tr>
<tr>
<td>$U$</td>
<td>coefficient of uniformity</td>
</tr>
<tr>
<td>$v$</td>
<td>flow velocity</td>
</tr>
<tr>
<td>$v_f$</td>
<td>filter rate</td>
</tr>
<tr>
<td>$v_{\text{advance}}$</td>
<td>advance rate</td>
</tr>
<tr>
<td>$V$</td>
<td>(total) volume</td>
</tr>
<tr>
<td>$V_H$</td>
<td>volume of voids</td>
</tr>
<tr>
<td>$V_{\text{machine}}$</td>
<td>initial injection volume</td>
</tr>
<tr>
<td>$V_{\text{extra injection}}$</td>
<td>extra suspension volume</td>
</tr>
</tbody>
</table>
List of symbols used

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>$V_{\text{annular gap}}$</td>
<td>annular gap volume</td>
</tr>
<tr>
<td>$V_{\text{pipe string}}$</td>
<td>subsequent injection volume</td>
</tr>
<tr>
<td>$V_t$</td>
<td>volume of solids</td>
</tr>
<tr>
<td>$w_s$</td>
<td>sinking speed</td>
</tr>
</tbody>
</table>
1 Basics

1.1 Basics and technical implementation of bentonite lubrication systems

Two basic types of bentonite lubrication systems are differentiated:

– Interval-controlled bentonite lubrication systems, in which the valves are controlled in a defined sequence.
– Volume-controlled bentonite lubrication systems (since 2014), in which the valves are controlled according to configured demand along the route; alternatively, the valves can also be controlled in a defined sequence.

Both systems exist both as systems integrated into the control container or as stand-alone systems.

In general, a lubrication system consists of the parts shown in Fig. 1.1. The first station in the lubrication circuit is the mixing tank, in which the bentonite suspension is dispersed before it is pumped into the storage tank. The bentonite pump supplies the individual lubrication points in the tunnelling machine and in the pipe string.

In an interval-controlled lubrication system, lubrication cycles are used according to the strategy of the machine driver. A lubrication point (see Fig. 1.2) consists of several injection fittings. The lubrication cycle starts these one after another (e.g. valve 1 – valve 2 – valve 3); thus only one valve is open at any one time. Then the next lubrication point is started.

Generally, normal cycle and extra cycle are differentiated. The normal cycle serves to lubricate the entire tunnel drive. The extra cycle permits in contrast additional control of separately selected lubrication points using the appropriate valves or injection

1) All the following statements, descriptions and illustrations refer to the technical systems of the company Herrenknecht AG for automatic bentonite lubrication.