2022/2023

Jackcontrol
monitoring microtunneling

1 Foreword

DEAR FRIENDS OF PIPE JACKING

Since the publication of our last complete catalogue in 2018, a lot has happened at Jackcontrol AG; almost no stone has been left unturned. In response to a broad demand from our customers for a comprehensive data management system for pipe jacking, Jackcontrol AG decided in 2019 to tackle this extensive and challenging project. After around two years of intensive development, we were able to launch our new **Microtunnelling Support System MSS** on the market in spring 2021 with great pride. MSS has since replaced our good old JCMonitoring software with resounding success. While the MSS basic package provides cost-effective basic equipment that is also suitable for simple and short tunnels, further options up to the **3D BIM option** can be selected on a project-specific basis, so that MSS meets almost all project requirements and can be used on all known combinations of pipe material and pressure transfer rings.

At the same time, the new MSS software requires much more powerful electronic hardware (computer, data lines, screen, etc.), so that a new hardware generation was also introduced with the launch of the MSS software. Here we developed the new hardware platform **MT.connect** together with our long-standing partner VMT GmbH, Bruchsal, Germany. MT.connect is completely compatible with the applications of VMT and Jackcontrol AG and will form the basis for many other applications in the tunnel over the next few years; the joint application brings considerable synergies and savings in time and costs. At the same time, MT.connect uses DSL technology and thus brings the large world of the Internet with its uncountable applications (e.g. LAN / WLAN, Internet telephony, VPN, video streaming, etc.) into the tunnel, which further makes everyday work on the construction site easier.

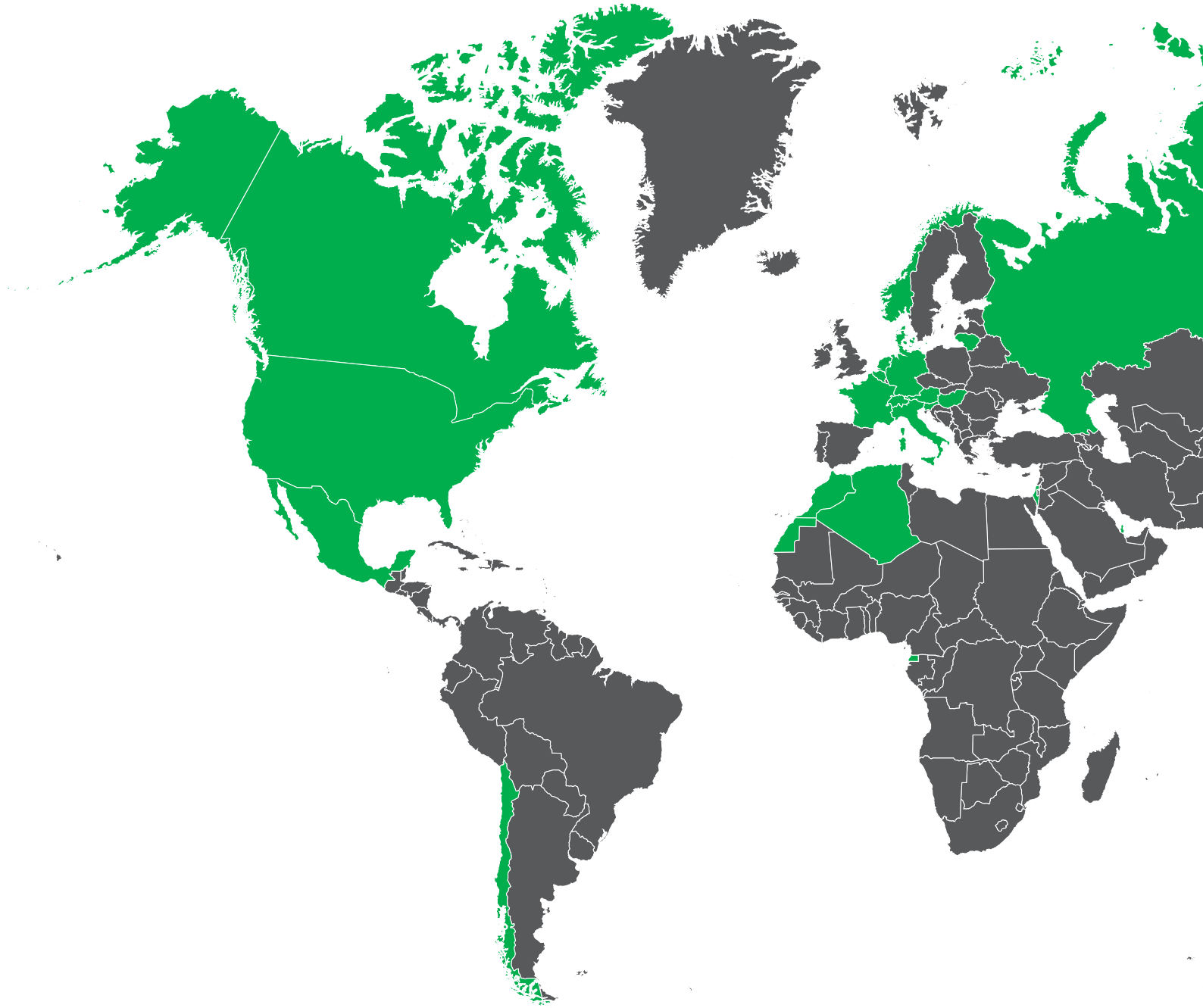
With the introduction of MSS, we are only at the beginning of a new era and MSS will continue to develop. This enabled us to consistently implement the new TUnIS navigation software from VMT on the MSS hardware in spring 2022 – with the joint solution **MSS^{TUnIS}** as the result. This means that data management, navigation and advance monitoring can be used synergistically in a coherent overall system on one and the same hardware. The new application **MSS.on**, which we have developed together with Herrenknecht and are currently launching on the market, is heading in a similar direction. With MSS.on, MSS and MT.connect are available in a permanently installed solution fully integrated into the Herrenknecht control containers, providing regular users with further cost and time savings.

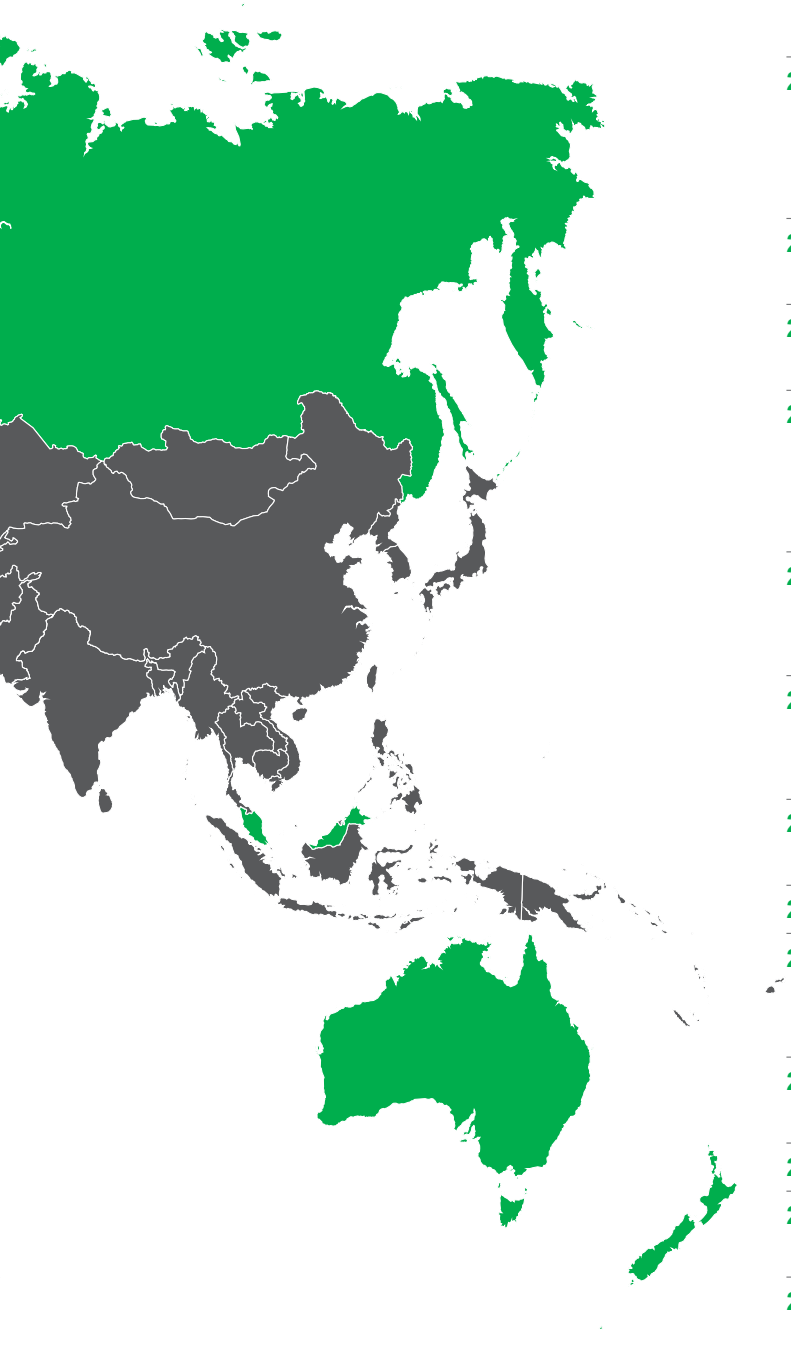
In addition to all the development in the area of software and hardware, we have also not forgotten the tunnel and are pleased to be able to present two new solutions in this catalogue, **JCGrout** and **JCFlex**, for joint finishing and internal joint sealing respectively - after all, we must not forget that with all the wonderful tunnelling technology, the pipe or the tunnel is the focus and represents the work ordered by the owner. Still in the range and no less important are, of course, the proven pressure transfer products **Hydraulic Joint** and **EDAR®**.

We hope you enjoy studying our new complete catalogue and are already looking forward to read from you and to a constructive cooperation with you!

Dr. Stefan Trümpi-Althaus

2 **Jackcontrol Milestones**





2005 **First application of Hydraulic Joint**
Hardstrasse Sewer, Zürich (Switzerland)

2007 **First application of Hydraulic Joint outside Switzerland**
Advance in Rothenburg ob der Tauber (Germany)

2010 **First application of Hydraulic Joint on steel pipe**
Schumann-Josaphat tunnel, Brussels (Belgium)

2010 **Smallest pipe diameter DN 800 mm, DA 1100 mm**
Crossing under SBB rail lines (Switzerland)

2011 **Highest jacking force with Hydraulic Joint (F = 26,000 kN) and longest Hydraulic Joint used (L = 35,550 mm)**
Advance in GKW Mannheim Block 9 (Germany)

2011 **Tightest curve radius (R = 80 m)**
Advance in Oslo (Norway)

2012 **First project in Middle East**
Tunnels of Muharraq STP, Manama (Bahrain)

2013 **Tunnels with the longest jacking pipes (L = 6.1 m), at the same time, first application of Hydraulic Joint in North America**
Advance in SARI Mainline Orange County (USA)

2014 **Tunnel with largest pipe diameter DN 3500 mm, OD 4200 mm**
Advance in Bottrop Boye, Emscher (Germany)

2016 **First application of Hydraulic Joint in Singapore, South-east Asia**
Advance T3003, MH94 – MH93 (Singapore)

2016 **First application of JCGrout cement injections**
Advance for Kraftwerk Cotlan, Rüti (Switzerland)

2017 **Introduction of EDAR®**

2018 **Longest tunnel and first application of Hydraulic Joint in Central America**
Altamira Landfall, L = 2224 m, Tampico (Mexico)

2018 **First application of EDAR® by Jackcontrol AG**
Zürich (Switzerland)

2018 **Introduction of RAM Mounting for Hydraulic Joint**

2019 **First application of Hydraulic Joint in Oceania**
City Rail Link, Contract 6, Auckland (New Zealand)

2020 **First application of MT.connect hardware**
Refurbishment Näppenschwilerbach, Mörschwil (Switzerland)

2021 **First planned use of MSS**
Montgelasstrasse Tunnel, Munich (Germany)

LAUNCH SHAFT PARIS (FRANCE)

3
Design and consulting

WE ARE MORE VERSATILE
THAN YOU MIGHT THINK

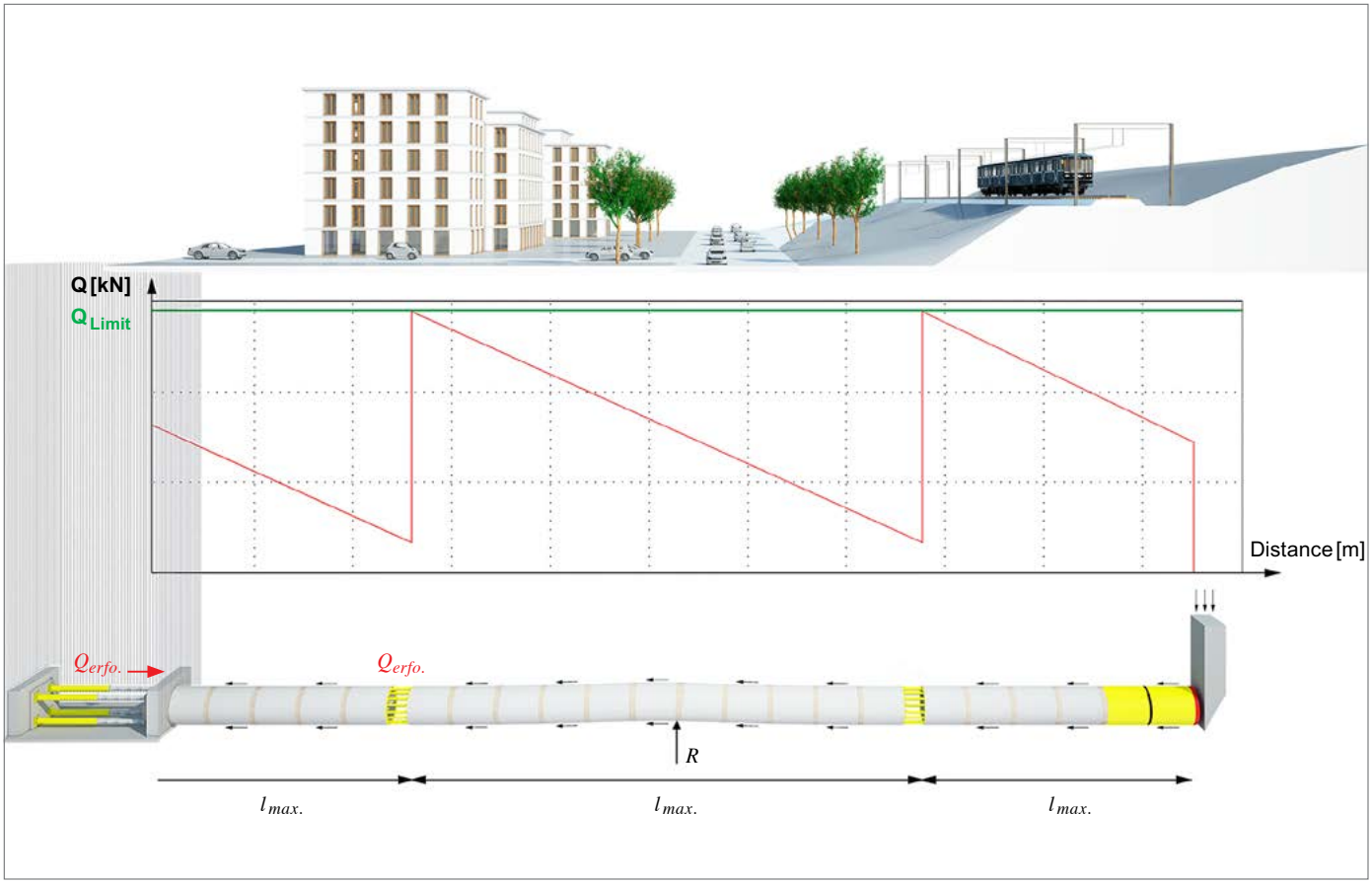
With our well-trained and experienced team of engineers, designers, draughtsmen and other technical experts, we cover a wide range of disciplines interactively:

- Structural analysis and design (steel structure, reinforced concrete, wooden structure)
- Geotechnical engineering and soil mechanics
- Water and oil hydraulics
- Machine construction and design
- Electrical engineering
- Measurement and control technology
- etc.

In the process if needed we think new ways and where possible try to make use of existing technical knowledge and experience – if necessary also from completely different technical areas. Our entire company history is characterised by the development of new products and applications, and accordingly we like to tackle new developments with the necessary portion of courage, innovation and respect.

TEST FACILITY FOR PRESSURE TRANSMISSION RINGS

REINFORCEMENT CAGE OF RC PIPE IN MOULD



In addition to the monitoring of running jacking operations with MSS, we can also take on the following tasks for you in all aspects of pipe jacking worldwide:

- Pipe design/structural analysis in accordance with all standards used worldwide (e.g. SIA, DWA, BS, ASCE, ASTM, etc.)
- Jacking force calculation
- Face pressure calculation
- Shaft structures in all soils and in groundwater using all technologies geotechnics
- Other aids such as crane slings, pipe bearings, auxiliary bridges, pipe arches, etc.
- Special solutions for pipe jacking
- Development of special applications
- Expertise

For this we have the best qualifications with our broad and deep experience and also current measurement software (such as Plaxis® or Cubus® programs).

We also support general contractors and clients in the area of planning for pipe jacking and microtunnelling as part of large projects. In the process, we can take on the complete design responsibility for planning and the associated services from the initial planning studies via the approval phase and execution to the final acceptance. We are happy to make our very broad experience of hundreds of mostly challenging executed Microtunneling projects and almost as many solved problems available to you.

Continuous further development of our capabilities and the application of new methods are a matter of course for us; for example, we also apply the BIM method on a daily basis and have also developed a corresponding software module for MSS (see also Chapter 4).

SHIPMENT OF JACKING PIPES (VANCOUVER, BC)

PIPE TEST RIG

LAUNCH SHAFT IN SECANT PILE WALL

FIELD FACTORY FOR JACKING PIPES, SWITZERLAND

AUXILIARY BRIDGE, SWITZERLAND

PIPE ROOF, SWITZERLAND

FLANGED STEEL PIPES, BRUSSELS (BELGIUM)

JACKING PIPES NORTH DAKOTA (USA)

REAL-TIME MONITORING ON JOBSITE

PIPE DAMAGE EXPERTISE

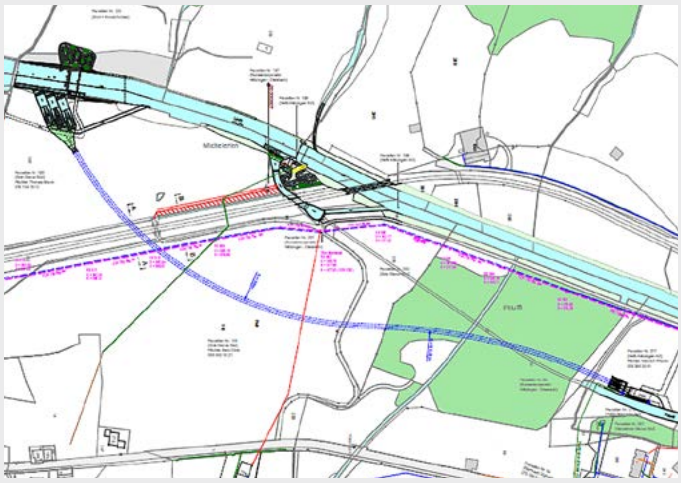
READY FOR SHIPMENT HYDRAULIC JOINTS IN GLARUS (SWITZERLAND)

Penstock for a river power plant in the Swiss Alps

The location and the geometry of the water intake at the river as well as the power house and water outlet into an existing channel determined the tangents at both ends of the penstock. Due to the maximum overburden of 14.3 m, the geology and groundwater conditions as well as the existing terrain (forest, creek), closed-shield microtunnelling was the only applicable construction method.

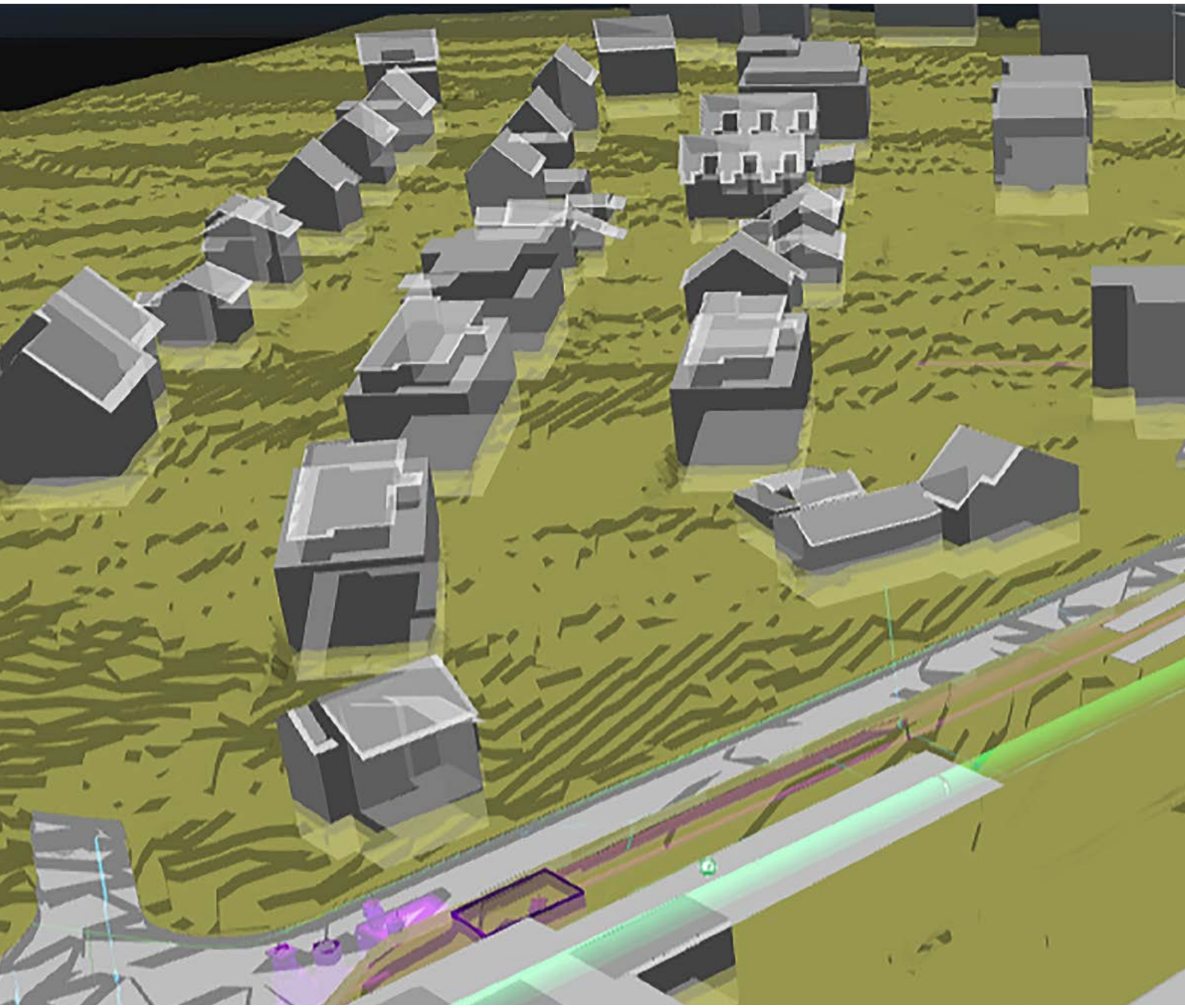
For hydraulic optimisation and due to existing infrastructure above and below ground, the optimal alignment for the penstock turned out to be an S-shaped curve in the horizontal with a steep vertical curve at the end of the advance to minimise the target shaft depth and thus the expensive dewatering systems.

The tight curve radius at the end of the drive, in combination with the large pipe diameter, resulted in large joint deflection angles, whereby the gap width on the inside of the curve was only 15 mm while a gap width of up to 75 mm was measured on outside of the curve.



SITUATION

AT A GLANCE	
Project name	Kraftwerk Rufi
Location	Hätzingen GL Switzerland
Purpose	Penstock
Completed	2016
Specialties	▪ Crossing under an arch channel ▪ Crossing under railway line / geomonitoring ▪ Small overburden
Total length	534 m
ID	3200 mm
OD	3800 mm
Alignment	3D compound S-curve
Minimum curve radius	260 m
Pipe material	Reinforced concrete
Pipe length	3 m / 4 m
Minimum overburden	below arch channel: 0.6 m below railway: 7.45 m
Geology and groundwater	Saturated debris, highly permeable, loose, sandy / silty gravel with cobbles and boulders. Groundwater level 4 m above pipe crown
Hydraulic Joint	JC250 / double loop. Admissible jacking force 22,000 kN / 2,240 t.
Guidance system	VMT SLS Microtunnelling LT
TBM	Herrenknecht AVND3000
Owner / Client	Hefti Hätzingen AG
Consultant / Designer	Jackcontrol AG, Switzerland
Tunnelling contractor	K-Boringen, Belgium



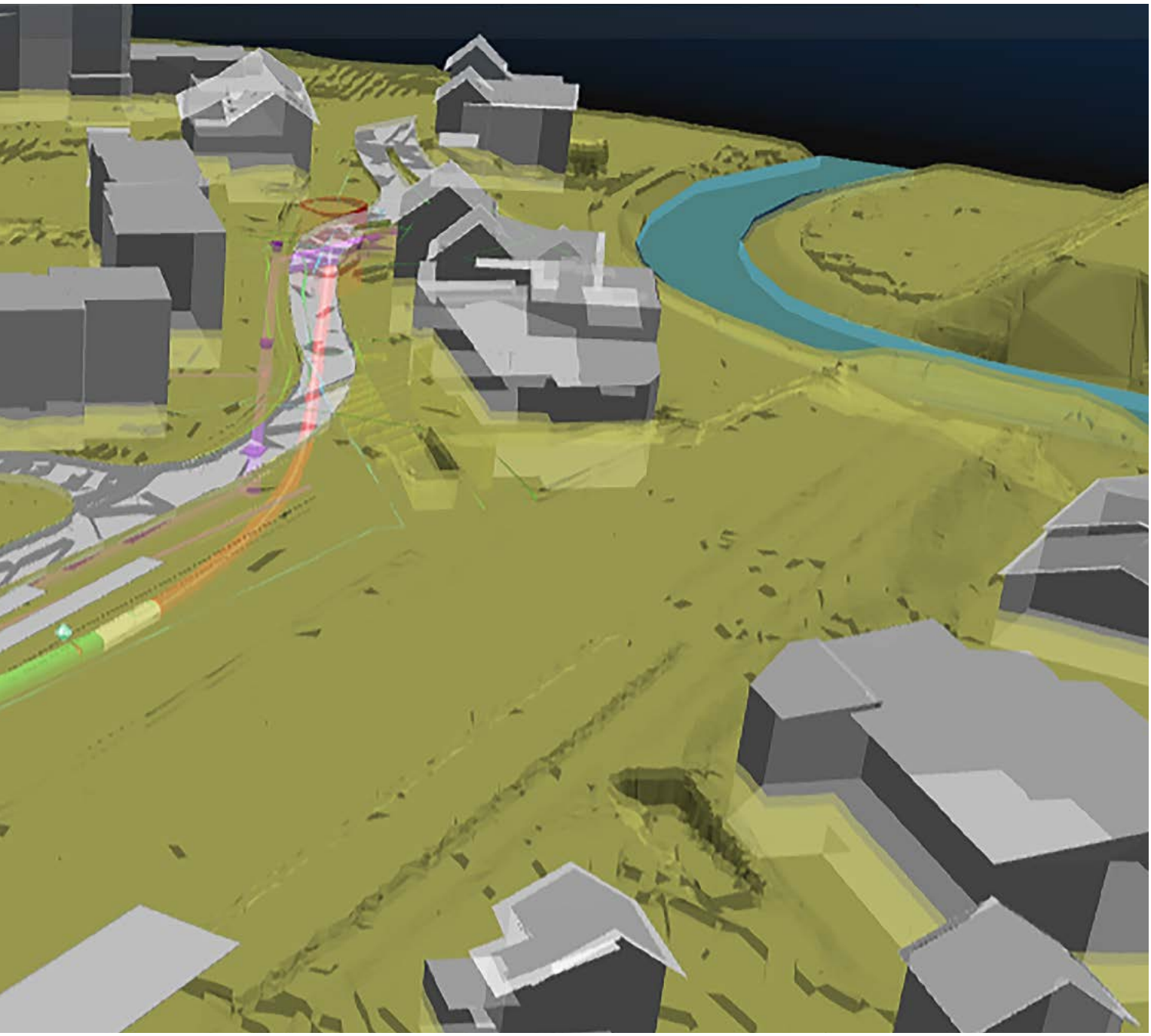
4 MSS
Microtunnelling Support System

4.1 OVERVIEW

The Microtunnelling Support System MSS supports the tunnelling contractor in the execution of ongoing tunnelling work and consists of the following main components:

- Browser-based MSS software
- Associated hardware including MT.connect tunnel hardware platform
- Project-related provisions of service and engineering.

MSS allows centralised, automated storage and management of all data generated during tunnelling (e.g. from the TBM, survey, pipe monitoring, guidance, annular gap lubrication, etc.) and makes this data available quickly

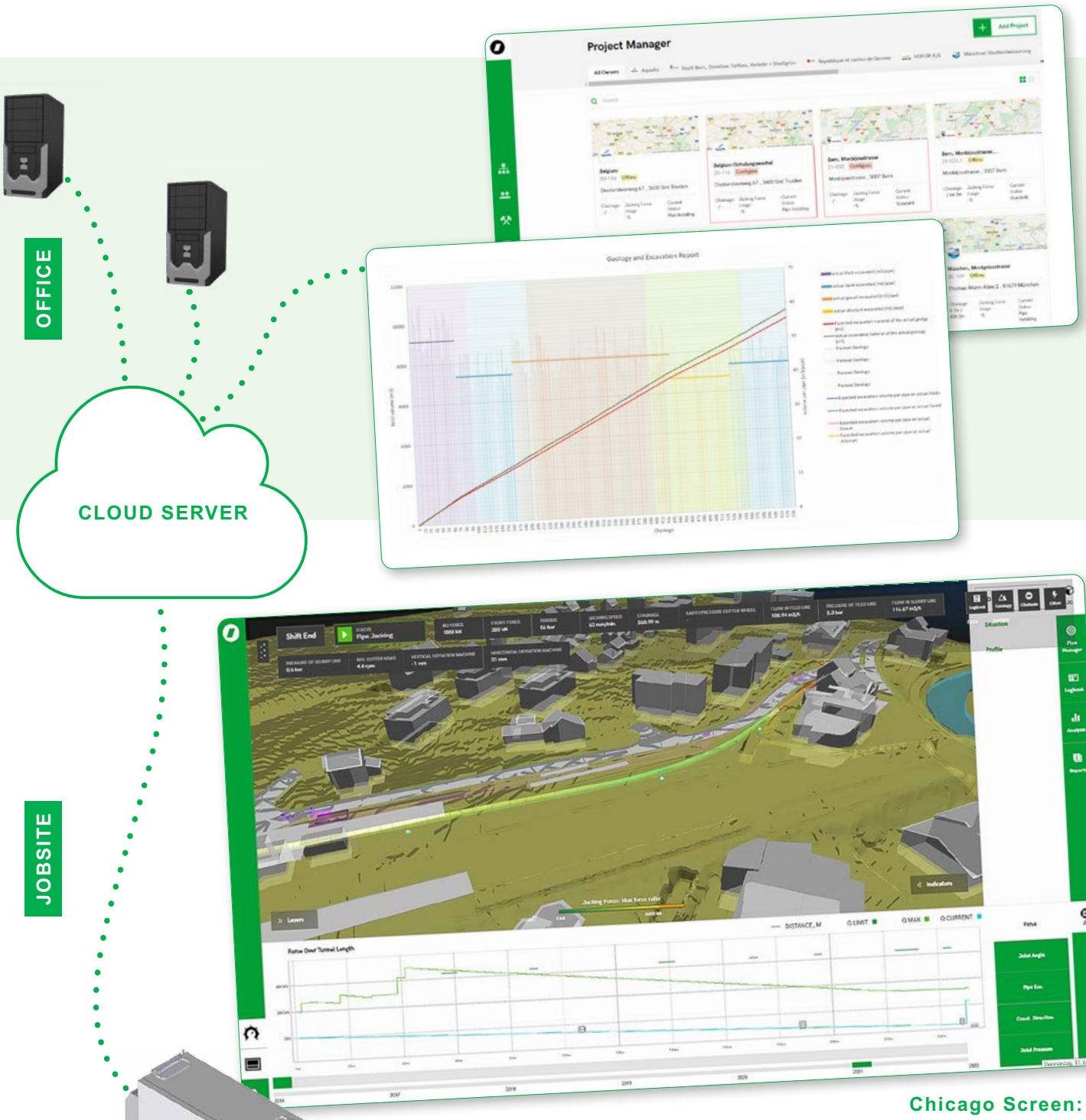


and easily in both graphical and numerical form. This allows the tunnelling contractor and the other project participants to carry out versatile and case-related evaluations and analyses of the ongoing tunneling process.
MSS has been specifically developed for the needs of pipe jacking and microtunnelling (as well as related processes such as DirectPipe®) and is characterised by the following main features:

- Simple and convenient data management
- Open system architecture for all available data
- Simple and intuitive application
- Fast and simple analysis functions
- Transparency for all persons involved in the project
- BIM compatibility
- Simple and convenient work reporting for tunnelling companies
- Monitoring of jacking pipes and pressure transfer rings

MSS has a modular design: While the Basic Package includes basic services that can be applied to almost any Pipe Jacking and Microtunneling project, the other MSS service packages can be activated according to the following overview of project requirements. The Project Manager creates the access portal and controls the access authorisations for the individual user.

MSS Overview



PROJECT MANAGER

- Entrance portal to MSS software
- Project overview
- Project preparation and configuration
- Live project support from Office PC
- Data management

Office Screen:
Customised for the office workplace

BASIC PACKAGE

- including MT.connect-Hardware and jobsite computer
- Database / data manager with permissions system to control data access for third parties
- open interface for all data on jobsite
- Project pseudo 3D visualisation
- Pipe Manager: pipe sequence plan continuously updated and pipe logistics support
- Report Manager: digital shift, daily, weekly and pipe reports in company CI
- Analysis tool for all numeric data

Option JCPipe®

- Pipe structural analysis and design including quality assurance documents
- Monitoring of statics / structural safety of pipes during the jacking process
- Automatic alarm

Option Navigation

- Processing and visualisation of navigation data
- Compatibility with TUnIS from VMT → **MSS**TUnIS

Option 3D / BIM

- Real 3D visualisation of jacking process and surroundings in real-time
- BIM-compatible documentation and jacking process

Option JackDirector®

- Analysis of the correlation between steering cylinder position and pipe joint angle
- prevents too strong steering of TBM

Option Hydraulic Joint

- pressure transfer ring for curved drives as well as for long and more difficult advances

Option EDAR®

- Elastomer pressure transfer ring, internal joint seal

TUNNEL HARDWARE

- compatible with VMT and Jackcontrol AG hardware, can be combined with the same cable
- Internet data transfer
- Internet in the tunnel for third parties (LAN and WLAN)
- Hybrid cable for power and signal
- Optional Joblight tunnel basic lighting
- simple and quick plug-in connection
- robust and suitable for underground use

MT.connect by

Jackcontrol monitoring microtunneling VMT

If required, Jackcontrol AG can also supply the pressure transfer rings required for a specific project (Hydraulic Joint and EDAR® options), whereby the Hydraulic Joint option can be used in combination with JCGrout cement paste injections. MSS can be used both for a single project (standalone solution / hardware for rent) as well as systematically for each drive of a company (company solution, hardware owned by the tunnelling contractor, see also chapter 4.3).

4.2 MSS SOFTWARE

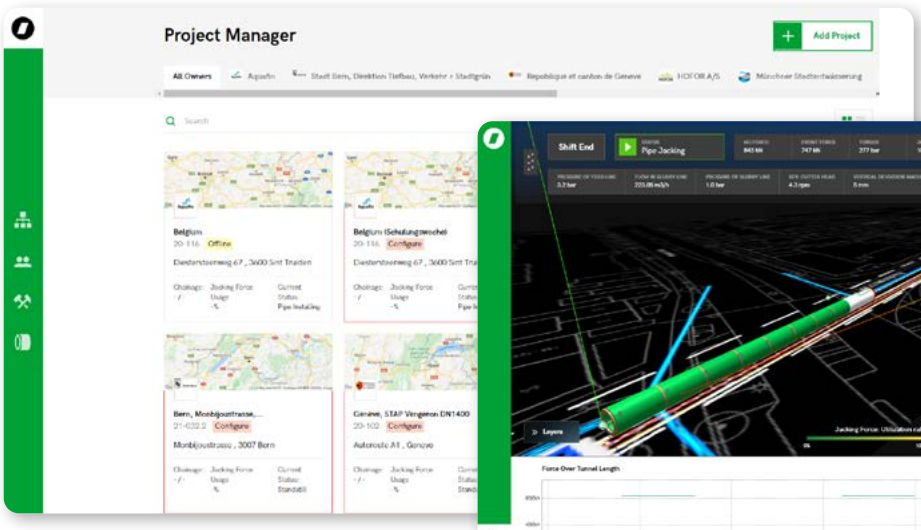
MSS service packages

MSS Basic Package

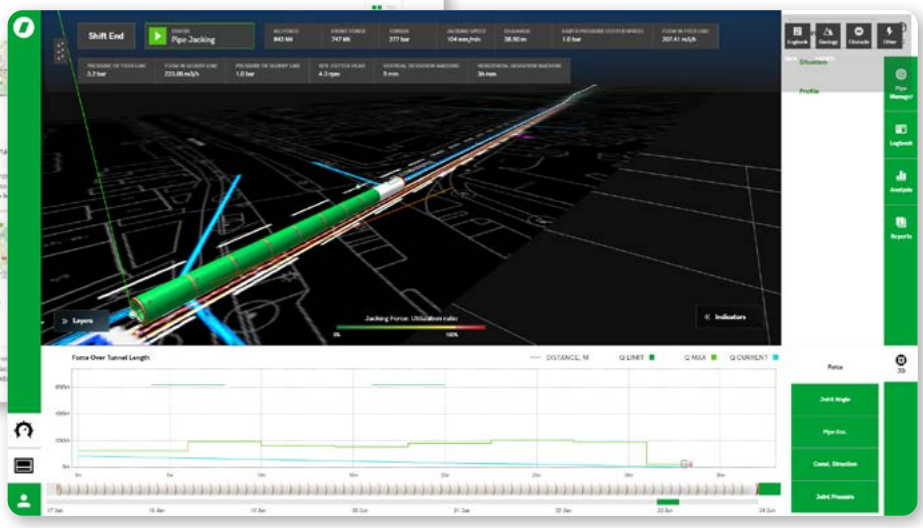
The MSS Basic Package includes the necessary software and hardware components as well as project-related services that support the tunnelling contractor in carrying out tunnelling work. In particular, the MSS Basic Package allows the recording and storage of data generated during the jacking process. These data can be displayed graphically and numerically in relation to the project and situation on the jobsite (Chicago Screen) and via a corresponding Internet access (Office Screen) and can be made available selectively to authorised third parties. The MSS Basic Package also provides the tunnelling contractor with numerous functions for process control and documentation.

The MSS Basic Package includes the following functions

- Hire of MSS hardware for the duration of the jacking process, including all components required for this (jobsite computer with touchscreen, MT.connect container box, MT.connect data cable (compatible with VMT surveying equipment), measuring wheel, pressure measurement of main presses, MSS boxes at each interjack and in the launch shaft). → If surveying is carried out by VMT GmbH, sensor data from VMT and Jackcontrol AG can be transmitted via the same MT.connect cable.
- Internet connection in the tunnel (via WLAN and LAN for each MSS Box / interjack). **This brings the wide range of Internet applications into the tunnel.** The provision of an Internet connection on the jobsite is not included in the scope of supply and is done by the tunnelling contractor.
- Interface to TBM data / logs (e.g. ANA interface from Herrenknecht, to be provided by the client).
- Data manager software for all tunnelling data, including: database, data management / control with selectable data access for authorised third parties such as site management, owner / client, etc.
- Browser solution with parallel software operation on jobsite computer and on cloud server, including backup data storage on Jackcontrol AG server, from which other project participants can also access data via login. Access to software and data from anywhere where Internet is available.



OFFICE SCREEN

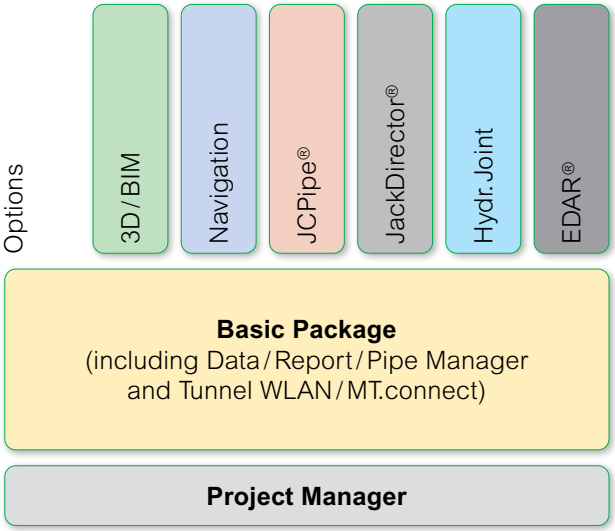


CHICAGO SCREEN

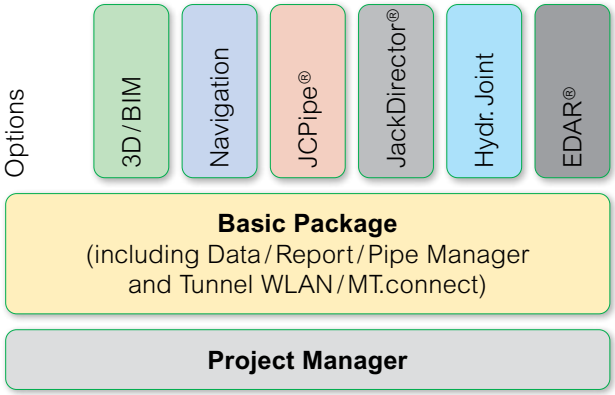
and services:

- Real-time visualisation of the jacking process on touchscreen in 2D and 3D. A comprehensive 3D display including BIM functions is optionally available for an additional charge.
- **Pipe Manager** with the following functions:
  - Pipe sequence plan generator.
  - Continuous tracking and updating of the pipe sequence plan with visual and tabular display.
  - Pipe Store Manager.
  - Recording and storage of all documents related to pipes (plans, data and quality assurance documents, photos, damage/defects, etc.) in option 3D/BIM.
- **Report Manager** with the following functions:
  - Automatic recording of machine data according to DWA-A 125, SIA 195 and other standards.
  - Provision of TBM data in reports for the attention of the client.
  - Construction journal/diary function on jobsite computer with fast, simple input editor on touchscreen **(so that nothing is forgotten that is important)** and feature to set markers/flags on electronic plan where extraordinary events have occurred (e.g. geological anomaly). Possibility of revision by the project manager of the tunnelling contractor.
  - Automatic or computer-assisted generation of various reports: pipe report, shift report, daily report, weekly report.
- Storage and management of reports.
  - The format and content of the reports can be customised within the scope of the company solution (see 4.4).
  - Management of access authorisation for third parties (owner/client, site management, etc.) can be set separately for the various reports.
  - Manual gathering, recording, storage and graphical display of additional data (such as weather data, excavation volume, noise level, oxygen content in tunnel, etc.).
  - Target/actual comparison of construction progress in graphical form.
  - Analysis tool for construction progress and all other recorded data series.
- **Analysis Tool** with the following functions:
  - Rapid provision of all numerical data recorded on the jobsite and stored in the database, graphically or in tabular form.
  - Various analysis functions.
  - Graphical replay function for all recorded data series, with regard to chainage (in kilometres) or time axis.
  - Output editor with feature to select and output data for further use (in PDF format).
- Jobsite installation and putting into service by Jackcontrol AG personnel.

STANDALONE APPLICATION



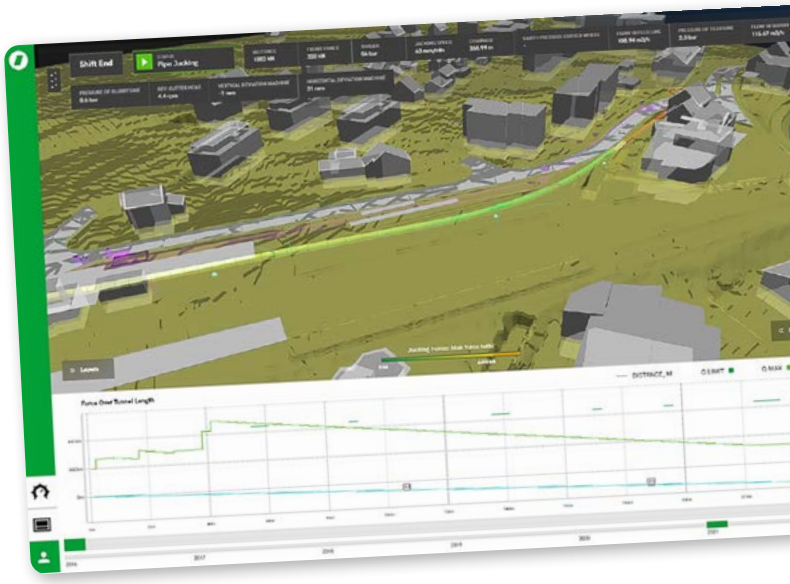
COMPANY SOLUTION



OVERVIEW OF MSS SOFTWARE PACKAGES

Service Package 3D / BIM

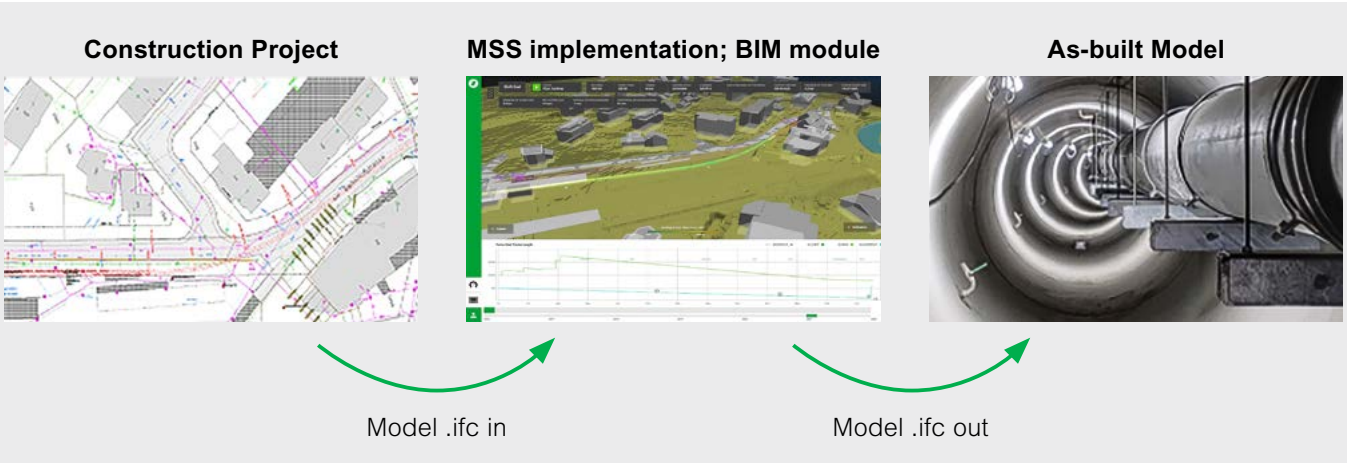
The Service Package 3D / BIM includes a three-dimensional display of the surroundings of the tunnel to be performed. The 3D model must be provided on site / by the tunnelling contractor, alternatively it can be generated by the CAD designers of Jackcontrol AG for an additional charge. The Service Package 3D / BIM also enables the recording and storage of all documents relating to the jacking pipes in electronic form (→ BIM attributes; e.g. pipe structural analysis, pipe plans, QC / QA documents, delivery notes, photos, etc.). These documents can be transferred to the client after completion of the jacking process.



3D VISUALISATION ON CHICAGO SCREEN

The Service Package 3D / BIM includes the following functions and services:

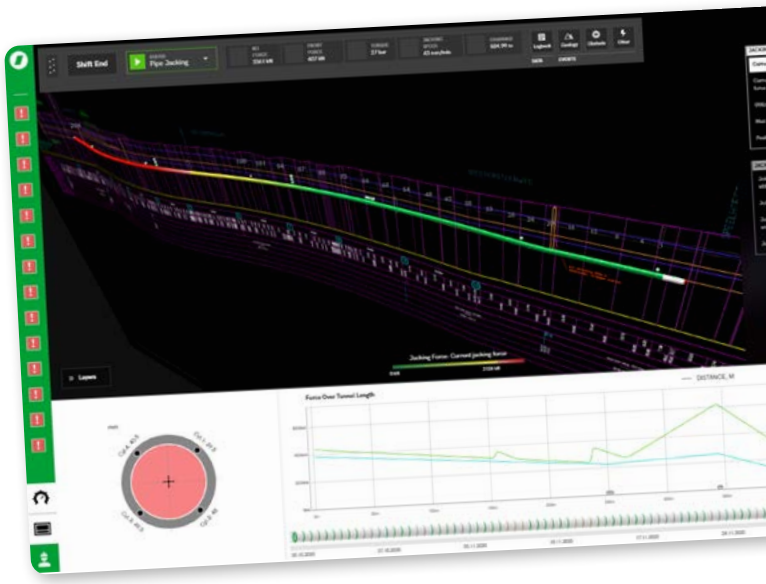
- Import of a 3D CAD model (normally to be provided by the designing engineer) of the jobsite environment in a project-related software set-up, including e.g. the following layers / component images:
  - planned tunnel axis (and actual axis, if option "Navigation" is in use)
  - Start and reception shaft
  - Geology
  - Buildings / structures in the surroundings
  - Land register
  - Surface
  - (and others).
- Three-dimensional and perspective graphical display of tunnel and surroundings on touchscreen in the control cabin / Chicago Screen.
- Simple and intuitive operation and setting perspective on touchscreen (Chicago Screen).
- Display and recording of BIM data, i.e. project attributes in addition to, for example, the pure geometry data, including:
  - Pipe plans
  - Pipe structural analysis
  - QC / QA documents from pipe production (e.g. pipe run sheets)
  - Other documents and records from advancing (e.g. photos, damage reports, etc.)
  - (and others).
- Provision of BIM data for transfer to the client as IFC model / plan.
- Support via telephone / remote maintenance (included) or on site if required.



OVERVIEW OF THE APPLICATION OF THE BIM METHOD IN MSS

The Service Package JCPipe®

The Service Package JCPipe® includes the dimensioning as well as the design of the jacking pipes and pressure transfer rings used. The scope of the services to be performed (e.g. pipe structural analysis, design of joining and sealing, etc.) as well as the applicable standards and guidelines are described further below. The Service Package JCPipe® also includes the monitoring of the current jacking process with regard to compliance with the dimensioning criteria taken into account in the dimensioning of the jacking pipes and the associated specifications to be complied with.



CHICAGO SCREEN WITH JCPipe® AND JackDirector®

The Service Package JCPipe® includes the following functions and services:

- Structural / geotechnical analysis with design statics and dimensioning of the jacking pipes, including structural safety, serviceability and other project-related criteria. The following standards and guidelines can be applied:
  - SIA 195
  - DWA-A 161
  - EN 1916
  - British Standard
  - ASCE 27-17
  - ASTM C76
  - etc.
- Applicable for the following pipe materials:
  - Reinforced concrete
  - GRP
  - Polymer concrete
  - Composite pipes (e.g. reinforced concrete with HDPE inliner etc.)
  - and combinations of these.
- Applicable for the following types of pressure transfer rings:
  - Timber (OSB, chipboard, etc.)
  - Hydraulic Joint
  - EDAR®
  - and combinations of these.
- Automatic, computer-based calculation of admissible jacking forces depending on the effective control movements (monitoring according to DWA-A 161 or Jackcontrol AG Limit Value Diagram for the Service Package Hydraulic Joint).
- Intuitively understandable display of existing and admissible jacking forces and joint articulation angles on the entire pipeline during the jacking process in real-time in 2D and 3D on the screen / Chicago Screen (with colour scale), in the analysis tool (in x / y graph) and also on individual pipes (numerically and x / y graph).
- Summary of the results in a final report showing the degree of compliance of the (structural) quality requirements for the jacking pipes.
- Hire of additional hardware and sensors (sensors, cables, MSS boxes) required in addition to the Basic Package.
- Jobsite installation and putting into service by Jackcontrol AG personnel (for standalone application).
- Support via telephone / remote maintenance or on site if required.

STRUCTURAL DESIGN
JACKING PIPE MADE OF REINFORCED CONCRETE

Service Package JackDirector®

The Service Package JackDirector® includes computer-based support of the shield operator for the control of the tunnel boring machine (TBM). Based on measurements made during the drilling distance travelled, the correlation between the steering angle of the TBM and the joint articulation angle of the consecutive pipes is determined. Based on this correlation, the maximum admissible steering angle for the TBM is specified, at which no reduction of the admissible jacking force determined in the Service Package JCPipe® is required. JackDirector® can only be applied in connection with the Service Package JCPipe®.

The Service Package JackDirector® includes the following functions and services:

- Project-related set-up of JackDirector® including data transfer of steering cylinders data from ANA interface (or steering cylinders equipped with own position sensors).
- Real-time display of the admissible range of steering cylinder positions on “Sight” on screen / Chicago Screen.
- Hire of additional hardware and / or sensors needed in addition to the MSS basic package and the Service Package JCPipe® (if required or data not available via ANA interface).
- Jobsite installation and putting into service by Jackcontrol AG personnel.
- Support via telephone / remote maintenance (included) or on site if required.

Service Package Hydraulic Joint

P-Type (see also Chapter 5.2)

The Hydraulic Joint is left in the structure after the jacking process has been completed and can be used as an internal joint seal as an alternative to impact seals. A sealing effect after tunnelling can only be achieved in connection with the implementation of JCGrout cement paste injections.

The Service Package Hydraulic Joint includes the following functions and services:

- Project-related design / Hydraulic Joint design (length, valves, filling quantity, fastening, cavity, etc.).
- Project-related calculation and specification of the admissible angular deflections and pressures in the Hydraulic Joints used as well as the maximum admissible jacking force.
- Check of the pipe joint design for the use of Hydraulic Joints (cavity, check of geometry of joint details in curve, etc.). Specification of correction proposals in the case of geometric incompatibilities.
- Plan development, pipe manufacturer information (cavity, rounding of cavity edges, etc.) and fastening of Hydraulic Joint on jacking pipe (RAM mounting).
- Production of Hydraulic Joints including filling with project-related filling quantity and previous vacuum degassing.
- Delivery of the ready-to-use Hydraulic Joint including mounting materials (RAM mounting as standard) to the jobsite, including packaging.
- Hire of additional hardware and sensors needed in addition to the Basic Package. Jobsite installation and putting into service by Jackcontrol AG personnel (for standalone application).
- Instruction of the jobsite crew in the installation and application of the Hydraulic Joint.
- Monitoring of the jacking process, presentation of the results in real-time visualisation on MSS software (only basic paramaters of the Hydraulic Joints: joint angle and pressure; further services and parameters such as calculation of admissible jacking forces, structural analysis / structural safety of pipes etc. are only provided in connection with the Service Package JCPipe®).
- Support via telephone / remote maintenance (included) or on site if required.

Remarks:

- The Service Package Hydraulic Joint can be applied only in combination with the MSS Basic Package.
- The Hydraulic Joint is installed on the jobsite by the site personnel using coupling springs (RAM mounting). Jackcontrol AG delivers the required assembly aids together with the Hydraulic Joints and provides them on loan.
- The customer is responsible for the provision of jacking pipes according to the specifications of Jackcontrol AG (cavity geometry and fastening, rounding of cavity edges, etc.).
- The Hydraulic Joint cannot provide any sealing function during the drilling operation. The tunnelling contractor must ensure that the Hydraulic Joints are not displaced from their planned position by hydraulic pressure acting from the outside of the pipe (e.g. pressure of the lubrication system or ground water pressure); this is particularly important when the pipeline is unloaded.

HYDRAULIC JOINT

Service Package EDAR®

(see also Chapter 5.3)

The Service Package EDAR® includes the following functions and services:

- Project-related design / EDAR® design.
- Project-related calculation and specification of the admissible angular deflections and maximum admissible jacking forces.
- Check of the design of the pipe joint for the use of EDAR®; specification of correction proposals in the case of geometric incompatibilities.
- EDAR® production including project-related conditioning.
- Delivery of the ready to use EDAR® including all mounting materials.
- Hire of additional hardware and sensors needed in addition to the Basic Package. Jobsite installation and putting into service by Jackcontrol AG personnel.
- Instruction of the jobsite crew in the installation and application of the EDAR®.
- Monitoring of the jacking process in progress, presentation of the results in real-time visualisation on MSS software (only functioning of EDAR® / joint angle; further services such as calculation of admissible jacking forces, structural analysis / structural safety of pipes, etc. are only provided in connection with the Service Package JCPipe®).
- Support via telephone / remote maintenance (included) or on site if required.

Remarks:

- The EDAR® is mounted during the pipe mounting in the start shaft. To do this, the pushing together of the pipes must be interrupted at a gap width of about 60 mm. The EDAR® is then installed in this gap by the tunnelling contractor using spacers and an assembly tool. Jackcontrol AG delivers the required assembly aids together with the EDAR®.
- The EDAR® cannot provide any sealing function during the tunneling. The tunnelling contractor must ensure that the EDAR® is not displaced from its planned position by the hydraulic pressure acting from the outside of the pipe (e.g. pressure of the lubrication system or ground water pressure); this is particularly important when the pipeline is unloaded.
- The installation of the further hardware / sensor units required in the tunnel after the start installation during the tunneling process is carried out by the tunnelling company. Jackcontrol AG supports the implementation via the monitoring system or by telephone and using remote access to the MSS software. During the initial installation, Jackcontrol AG installs the first sensor unit and instructs the jobsite crew so that they are able to install the remaining sensor units independently (applies to standalone application).
- **We strongly recommend the use of a pipe brake by the use of the EDAR® so that any increased elastic spring-back of the pipeline can be controlled.**
- When using the EDAR®, the pipe joint can be sealed after the jacking process using the JCGrout cement paste injections described in Chapter 5.4.

MSS^{TUnIS}

After the two long-standing partner companies VMT GmbH and Jackcontrol AG successfully launched the joint tunnel hardware platform MT.connect (see also Chapter 4.3) in 2020, another joint application, MSS^{TUnIS}, was introduced in 2022. MSS^{TUnIS} is the logical continuation of the path initiated with MT.connect of using the same hardware for Microtunneling navigation and data management / MSS / pipe monitoring, with the aim of making everything easier for the tunneling contractor to use and more cost-effective thanks to synergies.

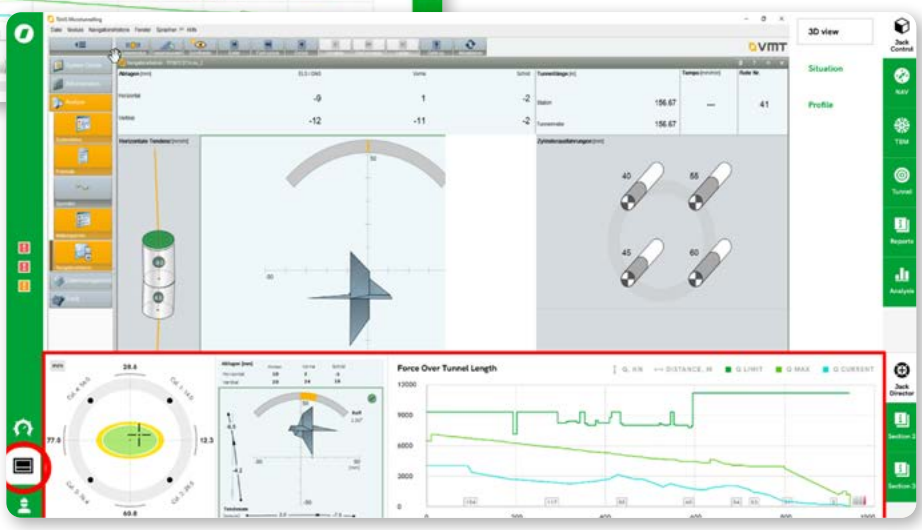
The MSS^{TUnIS} option requires the use of the tunnel hardware platform MT.connect (see also Chapter 4.3) as well as the current MSS computer including touchscreen. The two software applications TUnIS and MSS are operated in parallel on the MSS computer. With the MSS^{TUnIS} option, efficient remote access options ensure efficient support from both VMT GmbH and Jackcontrol AG.

During the jacking process, the most important navigation data together with the graphical display of the steering tendency are shown in real time in a separate TUnIS field on the Chicago Screen of MSS. If required (e.g. for settings or detailed evaluations), the TUnIS user interface can be used with full functionality on the Chicago Screen.

The MSS^{TUnIS} option provides the following advantages to the user:

- Optimum, intuitively understandable display at a glance for TBM operator.
- Synergies and cost-saving on the hardware side.
- Time saving for assembly and commissioning.
- Full integration of the guidance system into the data management.
- Optimum jobsite support.

CHICAGO SCREEN WITH MSS^{TUnIS} OPTION



MSS^{TUnIS} OPTION: FULL TUnIS FUNCTION ON CHICAGO SCREEN

4.3 HARDWARE

Overview

The set-up of the required hardware for the operation of MSS is shown in the picture below. While the MT.connect hardware platform equipped with VMT navigation equipment is used in the tunnel, the MSS software is operated on a computer designed for this purpose together with the associated touchscreen.

MSS Hardware

The MSS hardware consists of the following main components:

- MSS computer
- MSS touchscreen
- Internet connection.

The MSS computer and touchscreen can be installed on the surface, e.g. in the control container of the TBM, or also down in the tunnel, e.g. at the control cabin of an open shield.

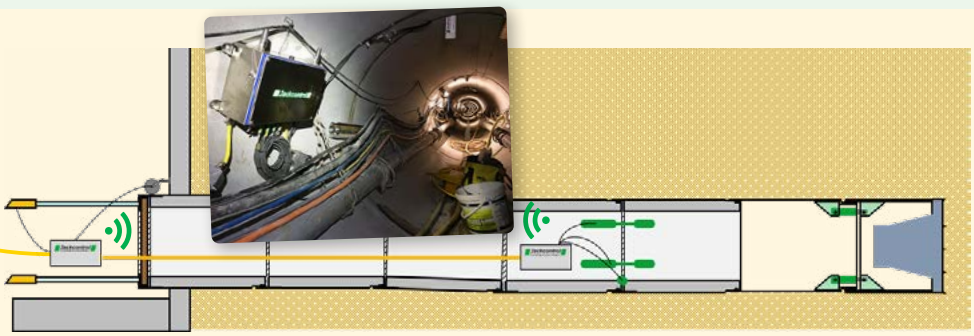
The MSS computer is a CAD-capable high-performance industrial computer with a powerful graphics card capable of displaying complex 3D plan models in smooth motion. For local storage of the large amounts of data generated during longer tunnels, the MSS computer is equipped with an adequate powerful memory card that allows the desired datasets to be displayed quickly. The MSS computer, together with all the necessary peripherals such as UPS, air conditioner, on/off switch, modem, slots, etc., is packed into a robust Rittal enclosure suitable for use on jobsite. The MSS touchscreen embodies equally high and robust industrial standards. With a flexible mounting, it can be easily installed in the control cabin in the field of sight of the TBM operator and, with a picture diagonal of 21.5 inches, provides the TBM operator with easy-to-read displays in good contrast. All the inputs can be made without any problems on the screen surface without a keyboard.

MSS COMPUTER

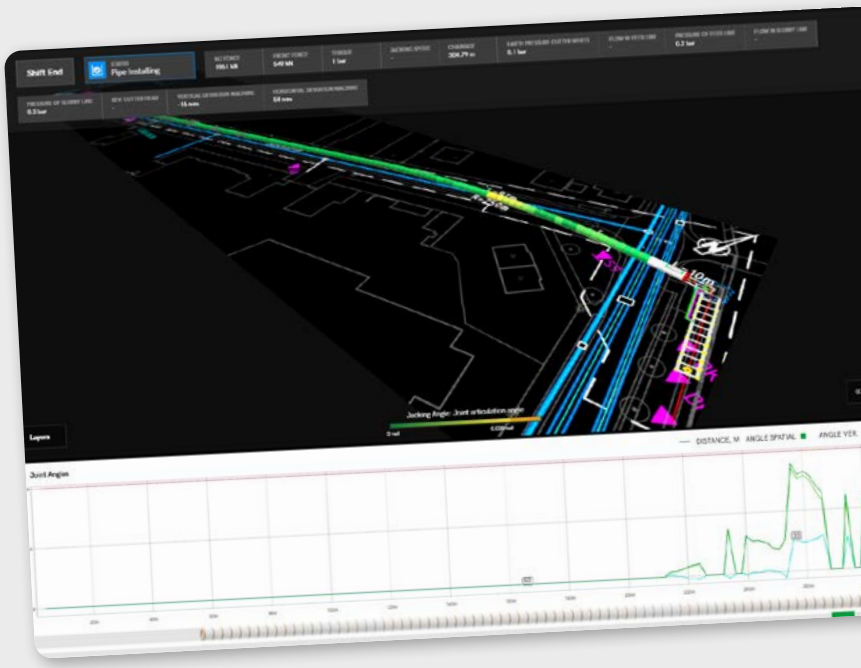
MSS HARDWARE

MSS TOUCHSCREEN INSTALLED IN THE FIELD OF SIGHT OF THE TBM OPERATOR

MT.connect

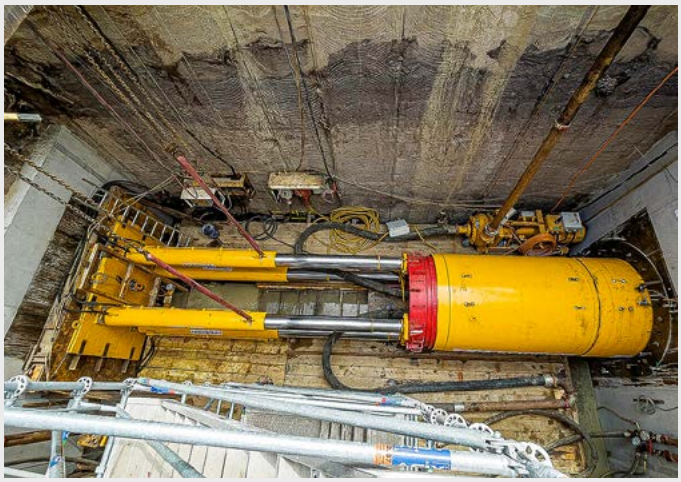


Sewer construction in the **settlement-sensitive** city centre of Tilburg (NL)



As a part of the Tilburg Delta Works Plan called “Blauwe ader” (ENG: Blue Sewer), the design-and-build project consisted of two microtunneling drives. The project was awarded by the City of Tillburg to the Belgian contractor K-Boringen. Main goal of the sewers was to better control the high-rain fall periods that caused major floods in the past.

Jackcontrol was commissioned with the monitoring of the project using MSS by the contractor. Although no Hydraulic Joints were used, several sensor units were placed in the tunnel to determine permissible jacking forces and steering deflections on strategic locations of the tunnel. Since the geology was known for causing high skin frictions in combination with high ground water pressure, lubrication was a key factor in order for the tunneling works to succeed. By measuring jacking forces over the entire tunnel length, lubrication could be performed on an accurate and precise way without causing lubrication blowouts or high jacking forces. Additionally, MSS was helpful for communication and safety purposes in the tunnel since pipe ID was relatively small in regards to the tunnel length.



START PIT

AT A GLANCE	
Project name	Blauwe ader: Rioolboring Enschotsestraat
Project location	Tilburg, Netherlands
Time of completion	2021
Specialties	settlement-sensitive geology, urban area, high friction, long distance in combination with small ID
Total length	848 + 305 m
Pipe ID	1600 mm
Pipe OD	1960 mm
Alignment	double s-curved
Min. curve radius	250 m
Pipe material	reinforced concrete
Pipe length	2 + 4 m
Geology & groundwater	fine sand groundwater present
Monitoring system	MSS (Microtunneling Support System)
Guidance system	VMT SLS Microtunneling LT
TBM	Herrenknecht AVND1600TB
Owner	City of Tilburg
Designer	(Design & Build contract)
Contractor	K-Boringen nv

MT.connect

MT.connect was launched in 2020 as a joint tunnel hardware platform by VMT GmbH and Jackcontrol AG and has the following features:

- Compatibility with all applications of VMT GmbH and Jackcontrol AG.
- Data transmission using DSL technology (Internet).
- Internet access in the tunnel via LAN and WLAN, also for third party users.
- WLAN coverage virtually in the entire tunnel.
- Robust, compact design and suitable for use in heavy underground conditions.
- High reliability.
- Simple and comfortable handling on the jobsite.
- Openness for data transmission from third party systems.

MT.connect consists of the following main components:

- MSS Boxes: These are usually installed at the intermediate pressing station (IJS) and include the connectors for the sensors and the LAN connectors and WLAN antennas.
- MT.connect system cable: Supplies MT.connect with power and also provides the Internet data transfer.
- Container Box: Provides power and data as an interface to the tunnel and at the same time forms the data interface to the computers of MSS (Jackcontrol AG) and TUnIS (VMT GmbH).
- MT.connect measuring wheel: Is used to measure the tunnel length and is connected to the Container Box.

MT.CONNECT BRINGS THE INTERNET INTO THE TUNNEL

MT.CONNECT MSS BOX INSTALLED IN THE TUNNEL

In addition, depending on the project requirements and the MSS service packages used, additional sensors (displacement sensors, pressure transmitters, measuring equipment) are connected to the MSS Boxes.

4.4 COMPANY SOLUTION

The company solution consists of a basic contract between the tunnelling company and Jackcontrol AG. It implements a systematic application of the MSS Basic Package by the tunnelling company. The company solution comprises the following features:

- The necessary MSS hardware for the MSS basic package (computer, touchscreen, MT.connect Container Box, MT.connect Tunnel Boxes with WLAN / Internet, MSS system cable, all compatible with VMT and Jackcontrol AG sensor technology) is purchased by and remains the property of the tunnelling contractor.
- The exact scope of the hardware is determined and offered on a customer-specific basis. The scope can include, for example, basic equipment for a 400 m long tunnel; additionally required equipment for longer tunnels or further service packages can be hired on a project-specific basis.
- The jobsite installation of the hardware is performed by the personnel of the tunneling contractor after they have been instructed for this by Jackcontrol AG. Ideally, the basic equipment (computer, touchscreen, Container Box) is permanently installed in the control container of the TBM so that the project-related installation effort is minimised.
- The functions of MSS are thus available to the tunneling contractor for each project at the discounted tariffs of the company solution.
- Company-specific set-up / design and content of reports are included as part of the company solution.

We would be happy to advise you about a possible company solution and look forward to developing a solution tailored to the needs of your company!

Refurbishment of Breitenrain track systems, Bern, Switzerland

Tight curve advance with WLAN

The existing combined sewers at Breitenrainplatz and Rodtmattstrasse date back to 1877 and 1905, respectively, and were in need of renovation and partially overloaded. The waste water authority of the City of Bern decided to replace that sewer by a DN1200 pipeline constructed by method of pipe jacking. This required three tunnels, with the first two tunnels being particularly challenging, with a minimum curve radius of only 150 m. Although the third tunnel had a bigger curve radius of 400 m, the type JC250 was used on all three tunnels for the sake of simplicity.

In addition, the new MT.connect tunnel hardware, which was developed together with the VMT company, was also used in this project. This new hardware makes it possible to share data cables and boxes between VMT and Jackcontrol, which simplifies handling on the jobsite. In addition, the time required for installation, configuration and maintenance is reduced. Last but not least, the hardware allows network infrastructure, lighting and power supply to be brought into the tunnel to enable communication and improve safety.

Finally, all three curved tunnels were retrofitted with cement paste injections JCGrout to passivate the collars and ensure a more durable joint connection.

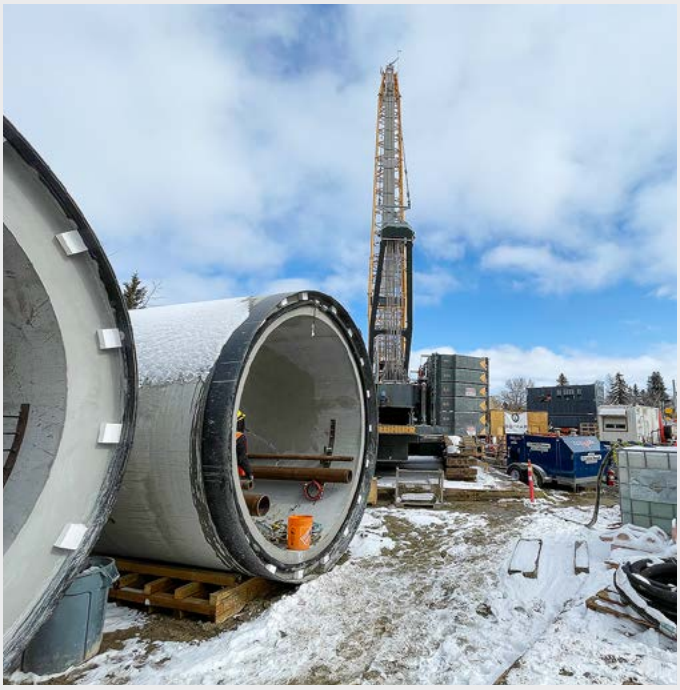
SITUATION

AT A GLANCE	
Project name	Refurbishment of Breitenrain sewer systems
Location	Bern BE, Switzerland
Use	Sewerage
Time of completion	2021–2022
Specialties	▪ complex alignments ▪ tight curve radii ▪ inner-city ▪ little overburden
Total length	243 + 138 + 174 = 555 m
Inner diameter	1200 mm
Outer diameter	1490 mm
Alignment	Curves, all three drives
Min. curve radius	150 m
Pipe material	Reinforced concrete pipes
Pipe length	3.00 m
Overburden	2.26 – 6.65 m
Geology	Artificial embankments / gravel fields / moraine / weathered molasse rock / lake sediments
Hydraulic Joint	JC250 with one loop
TBM	Herrenknecht AVN 1200
Owner / Client	Tiefbauamt der Stadt Bern
Tunnelling company	Braumann Tiefbau AG
Pipe manufacturer	Berding Beton GmbH Rheinsam plant

MSS conquers extreme winter conditions in Edmonton CAN

The Malcolm Tweddle and Edith Rogers Dry Pond and Sewer Improvements project was initiated in the Millbourne Urban Area. In the past, both surface and basement flooding had been reported by residents of this area. Increasing the conveyance capacity of the storm sewers was therefore proposed to mitigate the risks of future flooding in this area. The design asked for several tunnels performed by the trenchless microtunneling method. Therefore, contractor Bothar Inc. was awarded with the construction works.

The Microtunneling Support System (MSS) in combination with the Hydraulic Joint allowed the contractor to monitor several challenging aspects such as the high start-up forces due to a forced winter break, tight curve radii and relatively low ground coverage. The great advantage here is that possible problems were often discovered preventively. However, special congratulations go to the on-site team who managed to keep the tunneling process running 24 / 7 while the Canadian winter temperatures went down to –48 °C.



WINTER CONDITIONS ON SITE

INSTALLATION FIRST PIPE IN STARTSHAFT

AT A GLANCE	
Project name	Malcolm Tweddle and Edith Rogers Sewer Improvements
Project location	Edmonton, Canada
Time of completion	2022
Specialties	large diameter pipes and extreme winter conditions
Total length	835 + 189 m / 2740 + 620 ft.
Pipe ID	3000 mm / 118 in.
Pipe OD	3600 mm / 142 in.
Alignment	Curved
Min. curve radius	400 m / 1312 ft.
Pipe material	reinforced concrete
Pipe length	3 m / 10 ft.
Geology & groundwater	sandstone, clayshale and bedrock
Hydraulic Joint	JC260, single loop, admissible jacking force 20 500 kN
Guidance system	VMT SLS Microtunneling LT
TBM	Herrenknecht AVND2400 + ext. kit
Owner	EPCOR
Designer	AECOM
Contractor	Bothar INC.

TUNNELLING CONSTRUCTION SITE AT THE ZURICH AIRPORT (SWITZERLAND)

5 **Accessories** for jacking pipes

The pressure transfer ring – Key element in every pipe jacking project

5.1 **OVERVIEW**

Pressure transfer during the jacking process

The pressure transfer ring is a key element in pipe jacking. It has the task of safely transmitting the often very high jacking forces via the pipe elements. This is getting even crucial in curved alignment, where planned angular deflections of the jacking pipes occur, as well as in the case of unplanned steering movements, e.g. as a result of steering movements of the TBM or deviations from the planned axis due to geological factors. In addition, the pressure transfer ring must also compensate for geometric imperfections on the pipe face. Equally important is a coherent coordination of the type and characteristics of the pressure transfer ring used and the monitoring software used.

The MSS service packages Hydraulic Joint, EDAR® as well as the JCPipe-Package listed in the table on pages 36/37 provide the appropriate monitoring solutions for the safe and efficient execution of every microtunnelling

or pipe jacking project, independent of the jacking equipment used and tailored to the used pressure transfer equipment. In particular, curved drives, long-distance tunnelling and tunnels with straight or curved alignment in difficult hydrological or geological conditions or sensitive environments can be carried out with significantly lower hazard potential/risk by using these service packages. This applies to clients, planners and tunnelling contractors while ensuring high quality and workmanship at the same time.

The basis for each of these service packages is the proven MSS Basic Package together with the associated hardware, see also 4.2 and 4.3. This was originally developed for the use of Hydraulic Joints which on the one hand optimises the transfer of the jacking forces in the longitudinal direction,

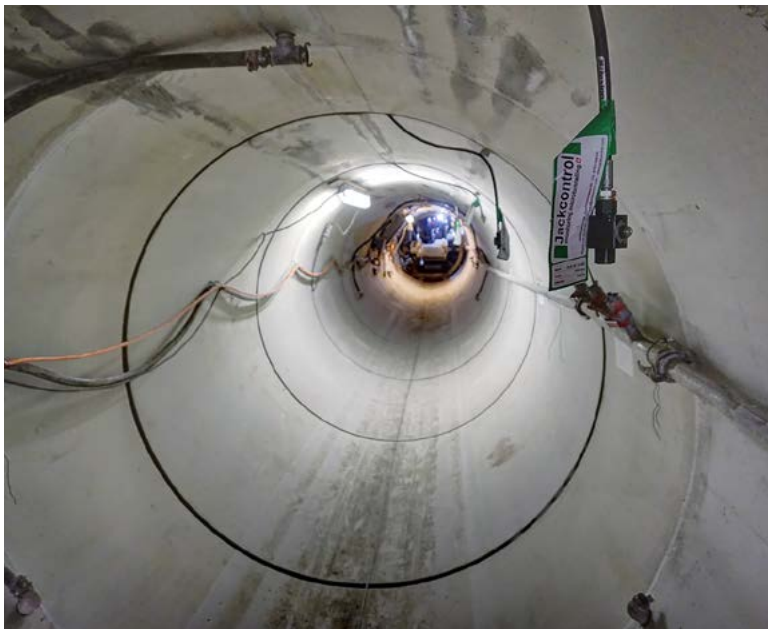
TIGHT S-CURVE IN THE CITY OF ZUG, SWITZERLAND

and on the other hand makes the determination of the state of stress in the jacking pipes possible in a simple and reliable way. For this, Jackcontrol AG uses knowledge gained at the Institut für Baustatik und Konstruktion at the ETH Zürich university about load and deformation behaviour as well as failure of reinforced concrete jacking pipes.

The Hydraulic Joint provides manifold options with regard to the structural monitoring of the jacking pipes. The system properties of the Hydraulic Joint allow a massive reduction of the risk of pipe damage compared to the use of conventional pressure transfer rings made of wood materials. At the same time, the installed jacking equipment / performance can be used optimally due to the knowledge of the stress state until the relevant limit values in the pipe segments are reached, without exceeding these limit values. The continuous recording of the relevant measured variables (joint gap widths between jacking pipes and fluid pressure in Hydraulic Joints) enables comprehensive documentation of the jacking process and, in particular, of the stress conditions in the jacking pipes, which provides those involved in the project with in-depth knowledge of the quality achieved in the finished pipeline; any pipe damage caused by the advance - if there is any at all when using the Hydraulic Joint - can thus be determined in a targeted manner.

The Hydraulic Joint allows a much larger joint articulation angle between the jacking pipes and thus much tighter curve radii compared to the use of conventional pressure transfer rings (PTR) made of wood materials, while maintaining the same pipe length and high jacking forces. Furthermore, the Hydraulic Joint in combination with JCGrout cement paste injections can be activated to be carried out from the inside of the pipe after the tunneling process in order to improve the leak tightness, for example in the case of leakage of the primary seal or also as a systematic seal to increase protection against leakage (see also Chapter 5.4 / 5.5). Thanks to an increase in the pH value in the area of the steel collar of the jacking pipe, the cementitious injection medium used in this process results in passivation and thus permanent corrosion protection of the steel collar.

Since the market launch in 2005, Jackcontrol AG has significantly expanded the range of possible applications for pipe jacking and microtunnelling with the Hydraulic Joint and the quality assurance based on it. After hundreds of mostly challenging Microtunneling projects successfully completed with Hydraulic Joints and the associated monitoring system, Jackcontrol AG met the customer need for an equivalent monitoring system for short and / or straight drives using conventional pressure transfer rings



ADVANCE IN COPENHAGEN (DENMARK)

made of wood materials and launched the JCPipe® package, which has already been successfully used in numerous advances. In 2017, Ingenieurbüro Baumgartner from Tuttlingen (Germany) and Jackcontrol AG agreed to take over the technology and distribution rights for EDAR® (Elastic Pressure Transfer Ring), which ideally complements the product range of Jackcontrol AG.

The modular design of the individual service packages listed in the table on pages 36 / 37 allows complete, real-time monitoring for all combinations of pipe materials and pressure transfer media in general use, whereby different pressure transfer media can also be used within the same tunnel. Depending on the project requirements, almost all standards and guidelines used worldwide in pipe jacking and Microtunneling can be taken into account, e.g. DWA-A 125 and 161, EN 1916, SIA 195, ASTM, ASCE, CSA, CPAA, PJA, etc. In particular, the JCPipe® package allows real-time monitoring of tunnels equipped with PTR made of wood materials, which, in application of the DWA-A 161 regulations, results in a higher admissible jacking force in conjunction with a significant reduction of risks compared to unmonitored drives. The pipe design can be carried out by Jackcontrol AG, but pipe designs by third parties (pipe manufacturers, designing engineers, etc.) can also be integrated.

The service packages according to the table below can be combined with each other, e.g. the Hydraulic Joint on a curved section at the end of a drive with the JCPipe® package on the straight remainder of the reach. The Hydraulic Joint can also only be used in conjunction with the MSS Basic Package in the case of simple and/or short drives. Only the indispensable monitoring of the fluid pressure and of the angular deflection of the Hydraulic Joint is performed in this case. Continuous monitoring of the pipe structure is performed when using the JCPipe®

OVERVIEW OF SERVICE PACKAGES

		SERVICE PACKAGE
		Range of application/description
MODULES	**PRESSURE TRANSFER MEDIUM**	
	PIPE STRUCTURAL ANALYSIS AND DESIGN	Static calculation of the jacking pipes, design of reinforcement and pipe coupling
	MOUNTING OF PRESSURE TRANSFER RING	**RAM** (standard, mechanical mounting, jobsite mounting)
		COL (exception/emergencies, gluing, factory or jobsite mounting; surcharge)
		KLEMM (with EPS spacer, jobsite mounting)
	SEALING MEANS BASED ON PRESSURE TRANSFER RING	In combination with cement paste injection **JCGrout** (see page 53, Chapter 5.4)
		Closed ring
	PIPE (including special cross sections such as kite profiles among others)	Reinforced concrete (with/without inliner)
		GFRP
		Steel
		Polymer concrete
		Vitrified clay
	MONITORING WITH MSS	
	ALGORITHM/ANALYSIS	
	MSS BASIC PACKAGE	
	USE OF JACK DIRECTOR®	

package. The JCPipe® package can be activated at any time if required (e.g. in the case of unexpected geological difficulties); this usually requires additional installations of measuring equipment (sensor units).

The EDAR® on simple and / or straight drives can be applied without MSS monitoring, whereby an upgrade is possible at any time.

HYDRAULIC JOINT PACKAGE	EDAR® PACKAGE	JC-Pipe® PACKAGE
Curved drives, tight radii, high requirements, internal joint seal	Curved drives, medium radii, medium requirements, internal joint seal	Straight drives and large radii, low requirements
Hydraulic Joint	Elastic Pressure Transfer Ring (EDAR®)	Pressure transfer ring (PTR) made of wood materials
(only with JCPipe®)	(only with JCPipe®)	✓
✓	×	×
(✓)	×	×
(✓)	×	×
✓	✓	×
×	✓	×
✓	✓	✓
✓ (in development)	×	✓ (without PTR)
✓ (flanged)	✓ (flanged)	✓ (flanged)
✓	✓	✓
✓	✓	✓
✓	✓	✓
Real-time structural and geotechnical verifications of jacking pipes (only in combination with JCPipe®)	Pressure transfer according to DWA-A 161 (only with JCPipe®)	Pressure transfer according to DWA-A 161
required	optional, use without MSS possible	required
possible	possible	possible

✓ INCLUDED AS STANDARD (✓) OPTIONAL / ALTERNATIVELY AVAILABLE × NOT AVAILABLE

Curve Microtunneling

The graph below provides quick and simple guide values about the minimum possible curve radii depending on the pipe dimension. More detailed planning aids are shown on page 43. Beside the jacking force transfer, various other project-specific factors determine the minimum curve radii. The Jackcontrol AG team is happy to advise planners and contractors about individual project development and helps to find the ideal combination of jacking pipe and pressure transfer medium for the specific project.

MICROTUNNEL IN CLEVELAND, OH (USA): ALIGNMENT OPTIMISATION WITH HYDRAULIC JOINT

Post Processing of Pipe Joints

The pipe joint also plays an important role in the structure after completion of the tunnelling work; it has the following important tasks during the service life of the tunnel:

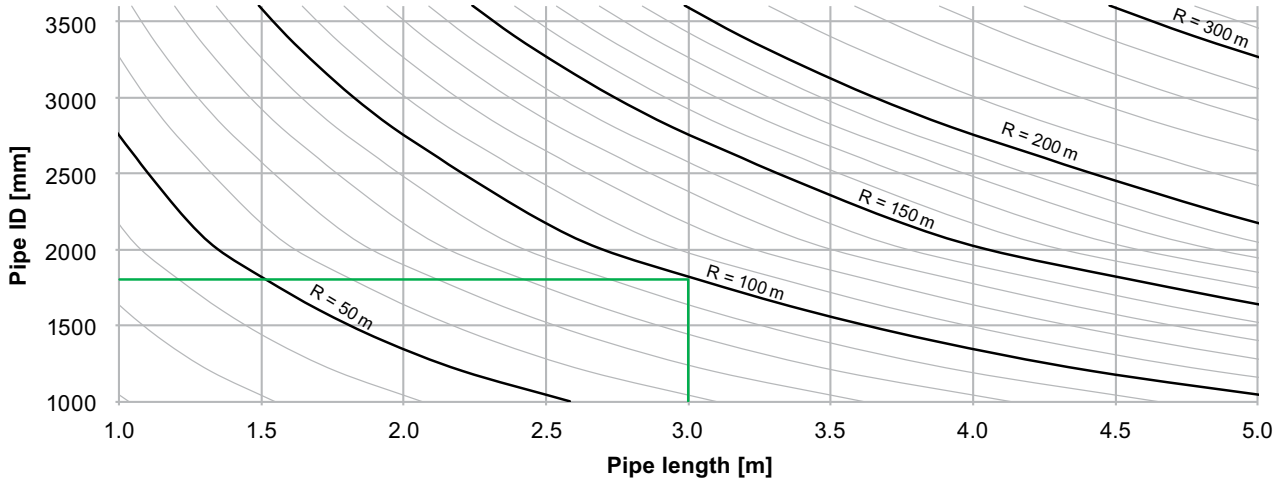
- Permanent sealing of the pipe line
- Equalisation of possible movements of the pipe/tunnel, e.g. due to differential settlements of the soil
- Internal joint seal
- etc.

While the mostly used sealing profiles made of elastomer/rubber prove themselves excellently, problems are repeatedly found in connection with pressure transfer rings made of timber and collars made of steel:

- Rotting of the wooden pressure transfer ring results in the formation of fungi/fungicides on the inner surface of the pipe.
- Rotting of the wooden ring results in snagging of floating debris in sewers/drains, associated with impairment of the hydraulic capacity of the sewer.
- Corrosion of the steel collar with long-term risk to the leak tightness of the pipe joint.
- etc.

With the two applications JCGrout (see 5.4) and JCFlex (see 5.5), Jackcontrol AG provides two solutions that involve the pressure transfer ring (Hydraulic Joint or EDAR®) to protect the pipe joint in the long term, also during the service life of the tunnel, in an uncomplicated and sustainable way with minimum working time in the tunnel and very high occupational safety for the personnel deployed in the tunnel.

MINIMUM POSSIBLE CURVE RADII



Example

How small can the minimum curve radius be selected for a jacking pipe of DN 1800 mm and a length of 3 m? Assuming a usual wall thickness (e.g. 180 mm), a minimum curve radius of 100 m can be advanced for a pipe length of 3 m.

CURVED MICROTUNNEL FOR HYDROPOWER PLANT (SWITZERLAND): R = 260 M (PIPE ID 3200 MM, L = 3 M)

5.2 THE HYDRAULIC JOINT

The advantages

- Higher jacking forces
- Smaller curve radii
- Longer jacking pipes
- Permanent, real-time monitoring
- Many intervention possibilities
- Systematic secondary joint sealing

The added value

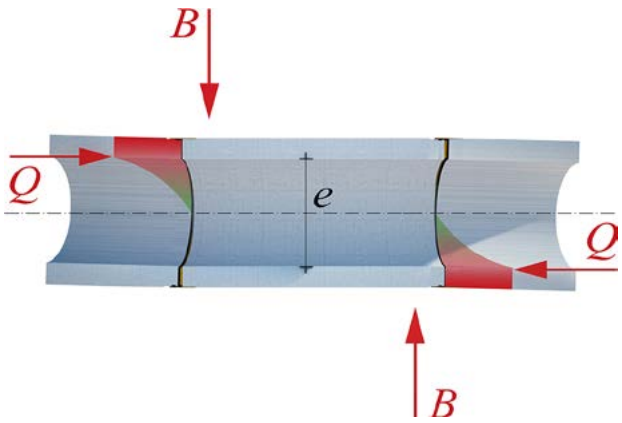
- Optimum quality assurance
- Minimal risk during jacking process
- Shorter construction times
- No need for intermediate shafts / installations
- Increased leak tightness of the pipe joints
- Wider range of applications
- More economical

Function

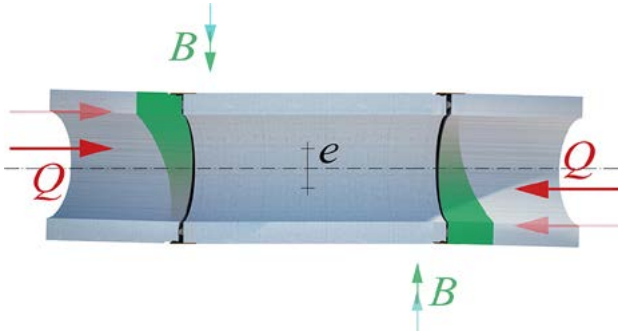
The safe transfer of the jacking force from pipe to pipe up to the tunnel boring machine (TBM) and tunnel face is essential in the microtunnelling and pipe jacking methods. The possibility of being able to transfer high jacking forces is indispensable for an efficient way of working.

Pressure transfer media made of wood materials prove their worth on straight tunnels. However, with larger joint angles and / or tighter curve radii, they reach their limits, i.e. only significantly smaller jacking forces Q can be transferred from pipe to pipe without damaging the pipes. Consequently, the admissible jacking force Q for articulated pipe joints and thus the jacking performance is significantly reduced. Articulation angles between jacking pipes occur not only as a result of planned alignment curvature, but also as a result of steering movements of the TBM, as a result of changing geological conditions and also as a result of manufacturing tolerances in the jacking pipes. The characteristic, irreversible material behaviour of a conventional pressure transfer ring made of timber results in stress concentrations on the inside of the curve when the pipe joint is articulated, which can exceed the strength of the pipe wall even at apparently small angles, while the joint on the outside of the curve is gaping and thus no jacking force is transmitted there.

HYDRAULIC JOINT INSTALLED ON A REINFORCED CONCRETE JACKING PIPE



STRESS DISTRIBUTION AND RESULTING JACKING FORCE PTR MADE OF TIMBER



STRESS DISTRIBUTION AND RESULTING JACKING FORCE HYDRAULIC JOINT

As a further consequence, the jacking force Q acts eccentrically on a jacking pipe affected by an angular deflection. Due to moment equilibrium, the affected pipe bears against the surrounding soil with the lateral reaction / bedding force B as a consequence: This lateral bedding force acts on the pipe in radial direction in addition to the external influences (soil load, water pressure or traffic loads). Investigations of reinforced concrete jacking pipes carried out at ETH Zurich between 2003 and 2005 have shown that these lateral bedding forces B are the main cause of the most observed pipe damage.

The Hydraulic Joint is used instead of a PTR made of timber It consists of a hermetically sealed hose line, which is normally applied to the trailing pipe face. The Hydraulic Joint is filled with non-compressible fluid. The Hydraulic Joint is compressed during jacking. As a reaction to the jacking force, the fluid in the Hydraulic Joint is pressurised and thus transfers the jacking force across the pipe coupling.

Obeying the hydraulic principle of communicating vessels, the same level of pressure exists throughout the Hydraulic Joint. Together with the reversible characteristic of the fluid cushion enclosed in the Hydraulic Joint, it is thus possible to tunnel with large angular deflections in the pipe coupling without stress concentrations and joint gaping. The jacking force is distributed much more evenly around the pipe circumference compared to conventional PTRs made of wood materials. As a result, the eccentricity of the jacking force and, proportionally, also the lateral bedding force B are significantly lower than with conventional PTRs made of wood materials. The smaller bedding forces and the elimination of stress peaks thus allow tunnelling with large joint angles without having to reduce the jacking force in order to maintain the structural integrity of the pipes.

Technical design of the Hydraulic Joint

The Hydraulic Joint consists of a hydraulic line adapted to the project-specific requirements. It is equipped with steel fittings at each end. One of the ends is only a pressure-tight dead end of the line. There is a ball valve at the other end, which is offset from the Hydraulic Joint with a short, thinner line. The ball valve has the following functions relevant to the operation of the Hydraulic Joint:

- Filling of the Hydraulic Joint at the factory
- Attachment of the pressure sensor for determining the fluid pressure in the Hydraulic Joint
- Controlled draining or pumping in of fluid during the jacking process
- Controlled draining of joint fluid after the jacking process

To ensure a sufficient pressure resistance, the Hydraulic Joint is reinforced with one or more steel wire meshes which are embedded in an environmentally compatible synthetic elastomer (e.g. NBR). The Hydraulic Joint is available in various sizes. The selection of the size depends on the curve radius, the pipe length, the wall thickness, the strength of the pipe material and the desired jacking force to be transmitted through the Hydraulic Joint.

The Hydraulic Joint is normally mounted as single loop on the pipe face. In exceptional cases, the number of loops can also be increased. Jackcontrol AG determines the most efficient configuration of the Hydraulic Joint for each project. If there are multiple suitable configurations, these are suggested as appropriate in the project planning. The maximum operating pressure of the Hydraulic Joint is specified with respect to the project so that it utilises the strength of the pipe material in an optimum manner while complying with adequate safety margins. For technical reasons, the Hydraulic Joint cannot be manufactured as a closed ring. Therefore, it always has two ends that are equipped with pressure-tight fittings in steel. These fittings require adjustments to the face of the pipe, see

also page 43. After the jacking process, the Hydraulic Joint is compressed while releasing the fluid and remains in the pipeline. However, it is also possible in particular applications to remove the Hydraulic Joint after the jacking process.

The fluid in the Hydraulic Joint consists of a mixture of water and antifreeze (biologically degradable). The necessary amount of fluid is a crucial parameter; it is determined and filled project-specific by Jackcontrol AG and Hydraulic Joints ready to install are supplied.

The Hydraulic Joint – Quality Assurance even after the jacking process

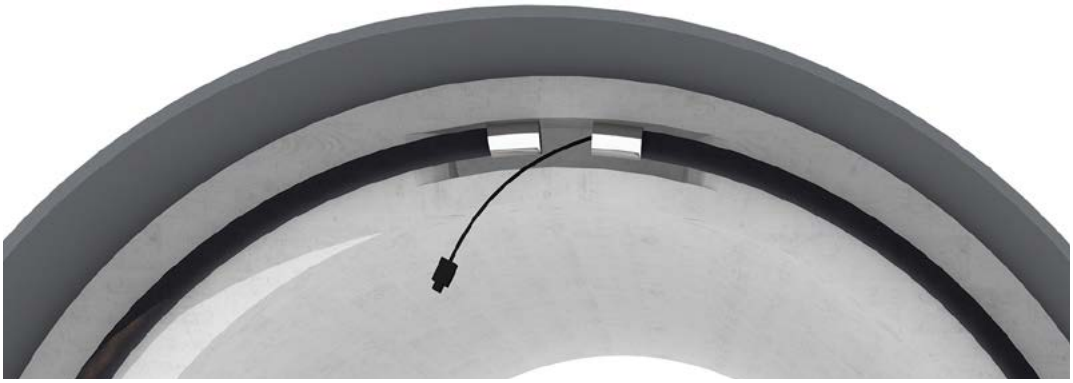
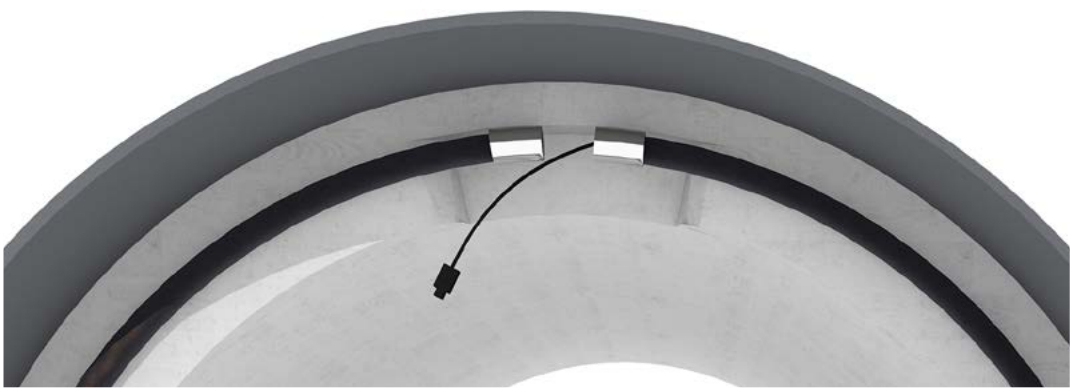
The Hydraulic Joint can continue to serve during the service lifetime of the structure to increase water tightness and/or as an internal joint seal. In combination with a cementitious injection, the sealing performance of the pipe joint can be significantly improved, and at the same time the cementitious injection material can decisively improve the corrosion protection of the steel collar of the pipe by increasing the pH value to the point that the steel is passivated, see also descriptions in 5.4 **(JCGrout)**.

Planning assistance for Hydraulic Joints

Dependent on the pipe geometry (pipe length and diameter) and the planned minimum curve radii, optimum combinations of pipe and Hydraulic Joint can be developed for the specific project. With the following diagrams on page 43, the possible curve radii in relation to the pipe length and pipe dimensions can be determined quickly and easily.

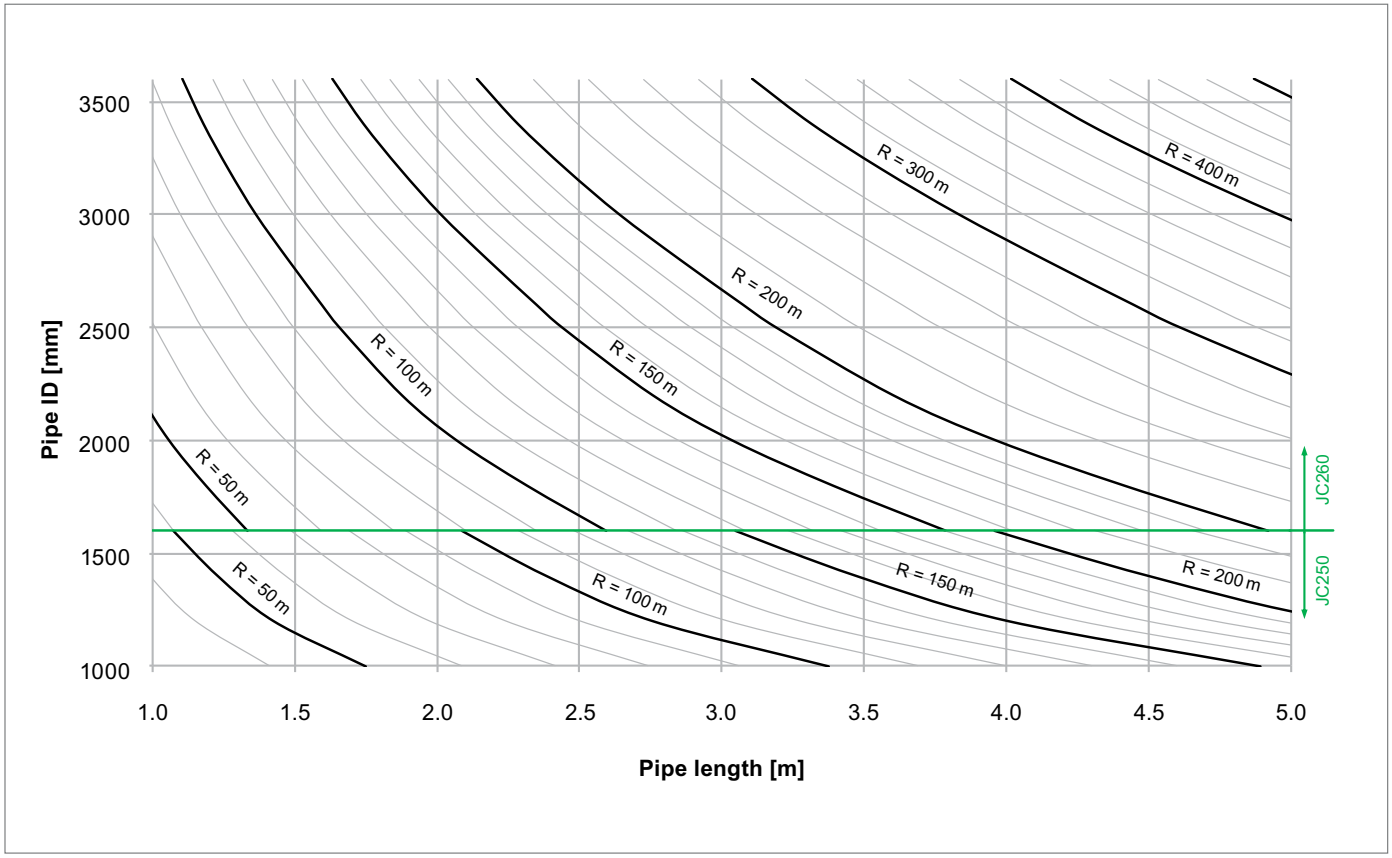
Pipe design (cavities)

To prevent the fittings of the Hydraulic Joint from being clamped between the faces of the pipes and the pipes from being damaged, cavities need to be made in the faces of the pipes. These cavities represent the only adaptation of the pipes needed for the Hydraulic Joint. There are the following types of cavities which are determined specifically for each project:

Cavity type	
Cavity integrated in pipe wall	
Cavity on the outside	

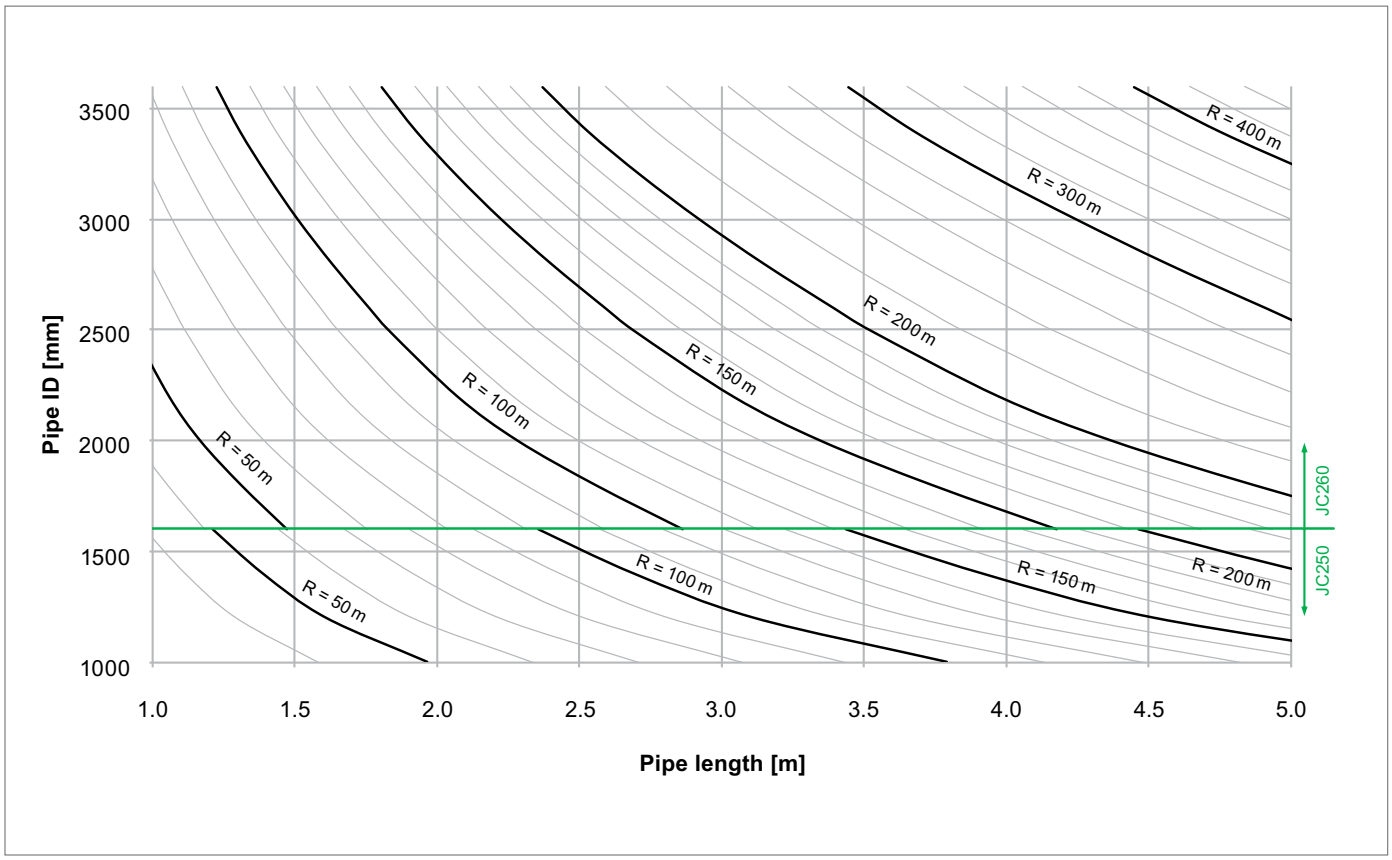
POSSIBLE CURVE RADII FOR HYDRAULIC JOINTS

(groutable)



POSSIBLE CURVE RADII FOR HYDRAULIC JOINT

(non-groutable)



RAM MOUNTING

HYDRAULIC JOINT WITH COL MOUNTING

These cavities are designed by Jackcontrol AG in coordination with the pipe manufacturers for each project and are shown in the respective plans. The arrangement and design depend on the following factors:

- Available space / wall thickness of jacking pipe
- Pipe joint finish after completion of the advance
- Subsequent cement paste injection
- Other, project-specific conditions (e.g. bottom channel, trolley transport of spoil, etc.)

The negative moulds and formwork inserts for the cavities can be made from steel, hardwood or plastic and are provided by the pipe manufacturer.

Installation of the Hydraulic Joint

There are two possibilities to attach the Hydraulic Joint to the jacking pipe; see also pictures above and table on the pages 36 / 37:

- RAM (standard) mechanical mounting, site mounting
- COL (exception / emergency cases): gluing, mounting on site or at pipe factory

These two types of mounting are explained in more detail below.

RAM mounting

The RAM mounting is a purely mechanical method and works without adhesives independent of weather conditions. It is characterised by simple handling and a high level of robustness. Mounting the Hydraulic Joint is simple and fast at the jobsite by personnel of the tunnelling company. The Hydraulic Joint is fixed in the cavity using a mounting bolt and a tensioning spring and is retained in the correct position with spacers clamped along the circumference of the steel collar. The RAM mounting can be carried out both as a preparation task next to the launching shaft or directly in the launching shaft when placing the jacking pipe.

COL mounting

With COL mounting, the Hydraulic Joint is glued to the rear face of the of the jacking pipe using a suitable adhesive. For a secure attachment, certain climatic conditions must be maintained for the bonding which requires a higher level of care by the personnel involved. For these reasons, COL mounting is usually carried out in the pipe factory. It is more complicated and therefore more expensive than RAM mounting but allows the supply of ready-to-use jacking pipes to the jobsite. COL mounting is mainly used in connection with Hydraulic Joints with multiple loops.

The Hydraulic Joint during the jacking process

Once the Hydraulic Joint is attached to the pipe, the jacking process can continue the same way as by the use of PTR made of wood materials. That means that the thrust ring of the main jacking station presses directly onto the Hydraulic Joint attached to the newly lowered pipe. It is only necessary to ensure that there are **no sharp edges** and burrs on the thrust ring that could come into contact with the Hydraulic Joint and damage it.

CAVITY FORMWORK ON PIPE SOCKET

PRESSURE TRANSFER RING (PTR) MADE OF TIMBER

During the jacking process, no manipulation of the Hydraulic Joint is necessary in most cases; it is basically maintenance free. For the sensor units, the Hydraulic Joint is used as a force sensor by measuring the internal pressure and the gap width of the Hydraulic Joint. Apart from the possibilities of the MSS monitoring and quality assurance system described from page 14 onwards, the use of the Hydraulic Joint provides further advantageous possibilities and options in special situations:

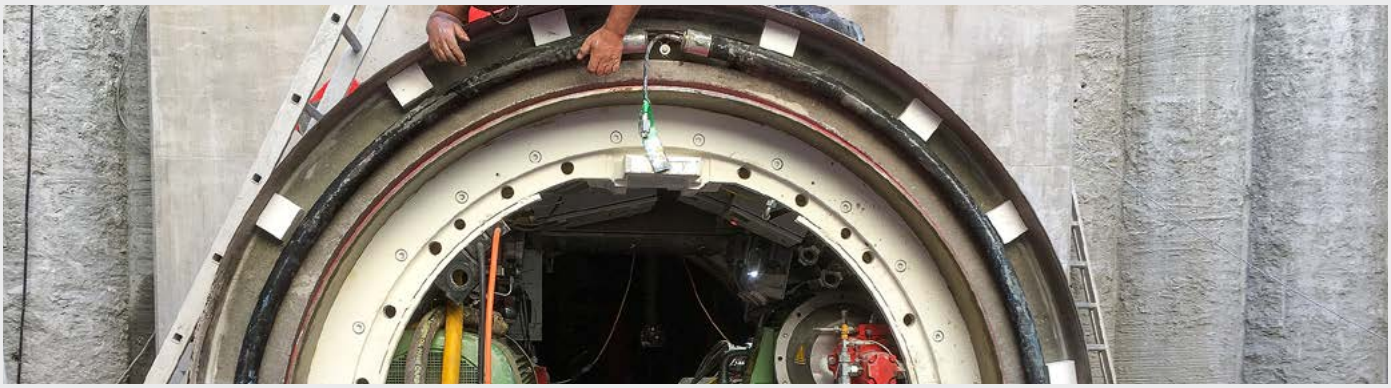
- The filling tap attached to the Hydraulic Joint allows the amount of fluid in the Hydraulic Joint to be changed or adapted to new conditions during the tunneling. For example, this can be necessary for unplanned adaptations of the alignment (e.g. a tighter curve radius than planned can make additional fluid necessary).
- The pressure can be measured at the tap at every Hydraulic Joint. In the event of a sudden increase of jacking forces due to local jamming of the pipes in the soil, this can help to locate the problematic area.
- A jammed pipeline can be released with selective emptying and filling of the Hydraulic Joint.
- By letting out joint fluid in multiple Hydraulic Joints along with the use of hydraulic spreading wedges available from Jackcontrol AG, space can be created between two pipes for interventions. For example, a damaged Hydraulic Joint can be replaced in this way.

Even after a completed breakthrough, the Hydraulic Joint remains easy to use. It is emptied to minimise the joint gap. This is accomplished by opening the ball valves in sections (from intermediate jacking station to intermediate jacking station). After opening, the respective advance section is moved / pressed together with the interjack or the main jack and the joints are emptied. The gap widths between the pipes thus become minimal on the inner side of the curves and on the straight lines. Afterwards, the interjacks are removed and also pushed together. The same procedure is performed with the following advance sections until all joints have been emptied and all interjack cylinders have been removed.

Finally, the parts of the Hydraulic Joint that are protruding into the pipe are removed. This normally happens at the same time as the deinstallation of the monitoring system.

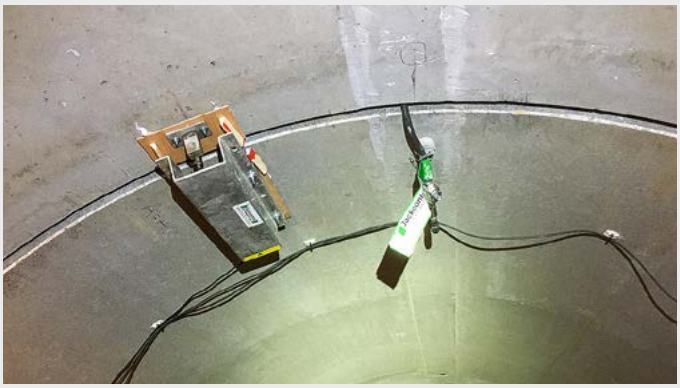
Emscher Genossenschaft / Gelsenkirchen, Holzbach BA2 SS

Hydraulic Joint type JC260 on large diameter pipes



The Hydraulic Joints type JC260 were used for the first time for projects with these dimensions. This type of Hydraulic Joint is often used for very tight curve radii in relation to the respective pipe dimension or length. The installation of the Hydraulic Joint on the jobsite, particularly as in the present case for large diameter pipes with accordingly large wall thicknesses, requires auxiliary means like a little scaffold. For this project, this work was carried out perfectly after appropriate instruction of the site crew.

Also special at this project is the mounting of the three displacement sensors by the use of mounting plates fixed by glue. This system has been used by Jackcontrol AG for many years. In the meantime, the system has been optimised to such an extent that the mounting also works smoothly upside down in the crown. The wooden plates, designed for one-time use, are easy to replace so that, as in this case, the sensors can be used for a next drive without great effort.



DISPLACEMENT SENSOR IN THE CROWN FIXED WITH GLUE

AT A GLANCE	
Project name	Holzbach BA2
Location	Gelsenkirchen, Germany
Use	Sewage main collector
Time of completion	2020
Specialties	▪ large pipe dimensions with single-loop Hydraulic Joint ▪ Structural analysis considering high inside pressure ▪ Mounting displacement sensors without anchor holes
Total length	164 + 290 = 454 m
Inner diameter	2400 / 2800 mm
Outer diameter	3000 / 3600 mm
Alignment	2 drives with curve
Min. curve radius	R = 300 m
Pipe material	Reinforced concrete
Pipe length	3.00 m
Max. overburden	8 m
Geology	Anthropogenic fill, weakly cohesive sand, silt and gravel layers, solid marlstone
Hydraulic Joint	Both drives JC260 with one loop
TBM	Herrenknecht AVND 2400
Owner / Client	Emscher Genossenschaft
Tunnelling company	Smet-Tunnelling nv
Pipe manufacturer	BERDING BETON GmbH

5.3 THE EDAR®

The **EDAR®** (Elastic Pressure Transfer Ring) is the ideal pressure transfer ring when it comes to simpler tunnelling with increased leak tightness requirements and / or internal joint seal. In 2017, Jackcontrol AG took over the EDAR® technology from Ingenieurbüro Baumgartner, Tuttlingen (Germany) and has further developed it. Namely, the EDAR®-S has been developed for smaller jacking pipes and the EDAR® has been implemented in MSS. It was also possible to simplify the installation of the EDAR® on the pipes. The EDAR® decisively extends the range of multi-functional pressure transfer media for pipe jacking and microtunnelling.

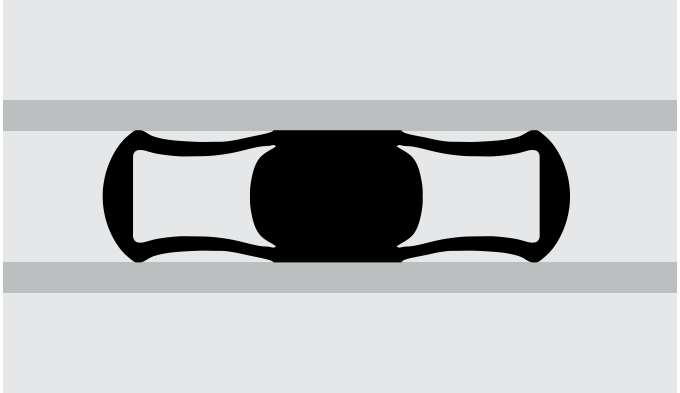
MICROTUNNEL IN COPENHAGEN (DENMARK): EDAR® ON DN 2500 MM PIPE

Overview and functionality

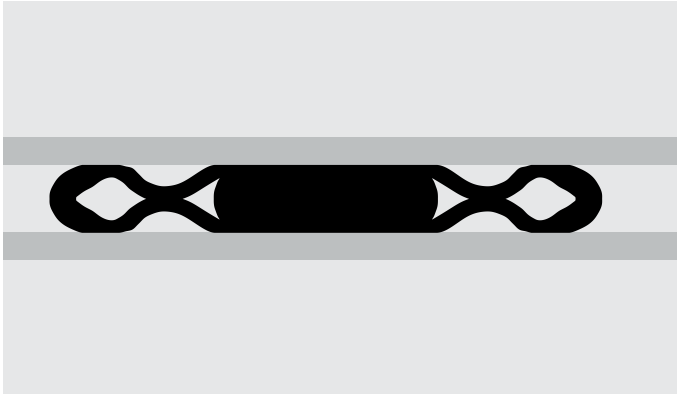
The EDAR® is formed from a pure elastomer profile that is glued into a closed ring. Similar to the Hydraulic Joint, the EDAR® provides a more even distribution of pressures over the pipe circumference when the pipe joint is articulated in comparison to pressure transfer rings (PTR) made of wood materials. The EDAR® was developed solely for this reason, with the mechanical properties of the elastomer material used and the profile cross section of the EDAR® forming the relevant parameters. Both – material properties and profile cross section – have been optimised with regard to the use of thick-walled jacking pipes. The profile cross section, which has been optimised over many years of trials and pilot applications, allows the splitting tensile forces acting on the jacking pipe to be limited to an admissible level.

Compared to conventional PTR made of wood materials, the EDAR® is characterised by the following relevant properties for the jacking process:

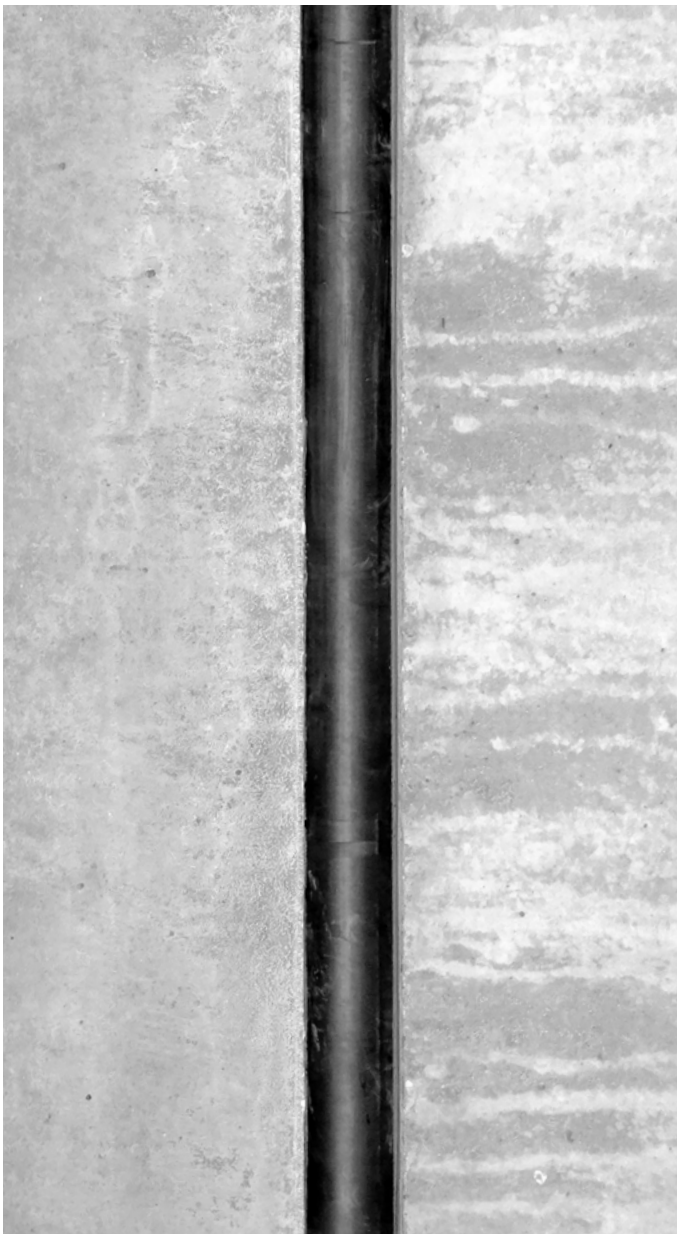
- Higher jacking forces in curves
- Longer jacking pipes in curves
- Reliable monitoring thanks to reversible mechanical properties



EDAR® UNSTRESSED



EDAR® UNDER LOAD / DURING JACKING



APPEARANCE OF EDAR® ON THE INSIDE OF THE PIPE

Beyond the construction phase, the EDAR® provides even more pro's during the entire service life of the structure:

- High quality and continuous joint sealing across the entire pipe circumference
- Internal joint seal with an inorganic, chemically inert and thus permanently stable material, even in the extreme conditions of a sewer (this in contrast to PTR made of wood materials that rot and promote fungus formation)
- In combination with appropriate pipe surfaces, the possibility of activation as an internal joint seal, depending on project requirements combined with injections / grouting

Jacking forces

The EDAR® has been developped to allow jacking forces in straight line drives comparable to conventional PTR made of wood materials. However, the EDAR® allows significantly higher jacking forces in curves than PTR made of wood materials due to its mechanical properties. In the process, joint articulation angles are only allowed to be so large that the contact area pipe – EDAR® – pipe is maintained across the whole circumference of the pipes (for even tighter curves, the use of the Hydraulic Joint is recommended). With the two types available, EDAR®-M and EDAR®-S, the following pipe dimensions can be jacked:

- EDAR®-S
  Pipe diameter: DN 1000 to DN 2000 mm
- EDAR®-M
  Pipe diameter: DN 2000 to DN 3200 mm

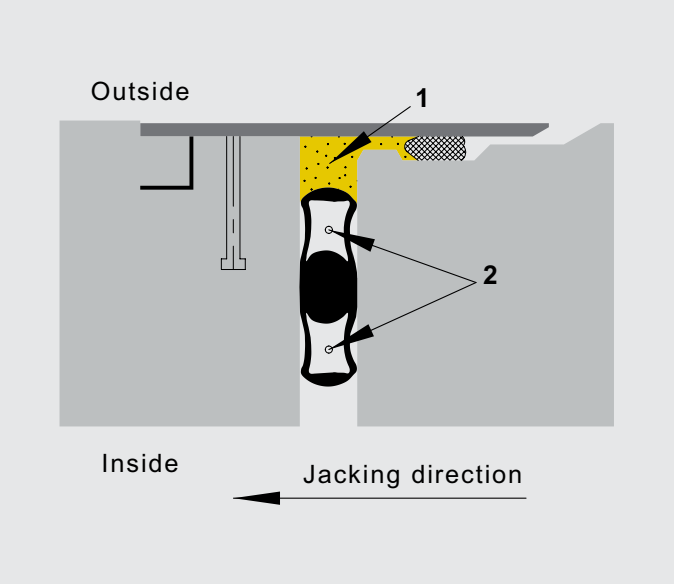
When using EDAR®, it is important to note that, in comparison to Hydraulic Joints and PTR made of wood materials, EDAR® has increased elastic recovery when the load is relieved and thus at a pipe exchange. For this reason, it can be necessary in some cases, mainly for longer drives, to use a **pipe brake in the launch shaft**. The Jackcontrol AG team is happy to advise you in this respect regarding your project. However, the same elastic properties also mean that after prolonged standstills and solidified bentonite in the annular gap, significantly lower jacking forces are required to bring the pipeline in move again, as every individual pipe starts moving again separately instead of a complete section between two interjacks at the same time.

The EDAR® as seal and internal joint closing

As the EDAR® forms a closed ring in permanent elastomer, it is primarily suitable as an inner joint closing, and – assuming appropriate pipe faces – also as an internal seal for jacking pipes, whereby in addition, depending on the application, the EDAR® can be activated for sealing using additional injections in the annular gaps in the EDAR® or between the EDAR® and the steel collar.

The annular gap (1) between the EDAR® and the steel collar is filled with **JCGrout** cement paste injections analogous to the Hydraulic Joint, see also 5.4, preferably using grouting nozzles previously installed in the pipe wall for filling and venting. It is worthwhile pointing out here again the resulting, high-quality corrosion protection for the steel collar due to the high pH value and passivation of the steel.

Both closed annular spaces inside the EDAR® profile (2) are drilled into after the jacking process for the purpose of the **JCGrout** injection and equipped with a packer. Afterwards, cementitious injection material can then be pressed in under increased pressure, which sets the EDAR® under longitudinal tension and thus significantly increases the sealing performance. After the injection, the packer is closed and the cementitious injection material can harden, which effectively “freezes” the tension state / preload. With **JCGrout**, it is important to ensure that the end areas of the pipeline are adequately held or anchored in the longitudinal direction of the pipe at the end shafts, as otherwise there is a risk that the pipes will move in the direction of the end shafts as a result of the injection pressure, which is usually undesirable and would prevent the build-up of the prestressing.



SCHEMATIC DIAGRAM FOR INJECTIONS:
POSSIBLE INJECTION CHAMBERS

Planning the use of the EDAR®

Both of the diagrams shown below clearly illustrate the range of application for the EDAR® based on the pipe geometry . According the German Code DWA-A 161, lower tolerances in the pipe geometry and steering movements can be assumed if the joint articulation angles are measured and taken into account. When using them, the two diagrams below result for the EDAR®-S and the EDAR®-M which, based on the pipe geometry, show the minimum possible curve radii.

Pipe design

The EDAR® can be used without any adaptations on every thick-walled jacking pipe. As a result, the EDAR® can be used on an impromptu basis in every phase of a running jacking operation.

Use of the EDAR®

The EDAR® is easily installed during the installation of a new jacking pipe in the launch shaft by briefly interrupting the pushing of the new pipe to its precursor when the gap between the leading and trailing pipe is about 6 to 8 cm. In this position, the EDAR® is laid in or clamped into the open joint gap. Fine adjustment of the correct position on the pipe face is done using lightweight spacers which are also placed in the joint gap. Once the EDAR® is correctly positioned, the incoming pipe is joined completely and the jacking process can be continued.

During the jacking process, the EDAR® does not require any further measures. However, the elastic recovery associated with the release by the lowering of a new jacking pipe needs to be minimised and controlled by appropriate use of interjacks and pipe brake. With some experience it is also possible to install a new pipe without activating the pipe brake.

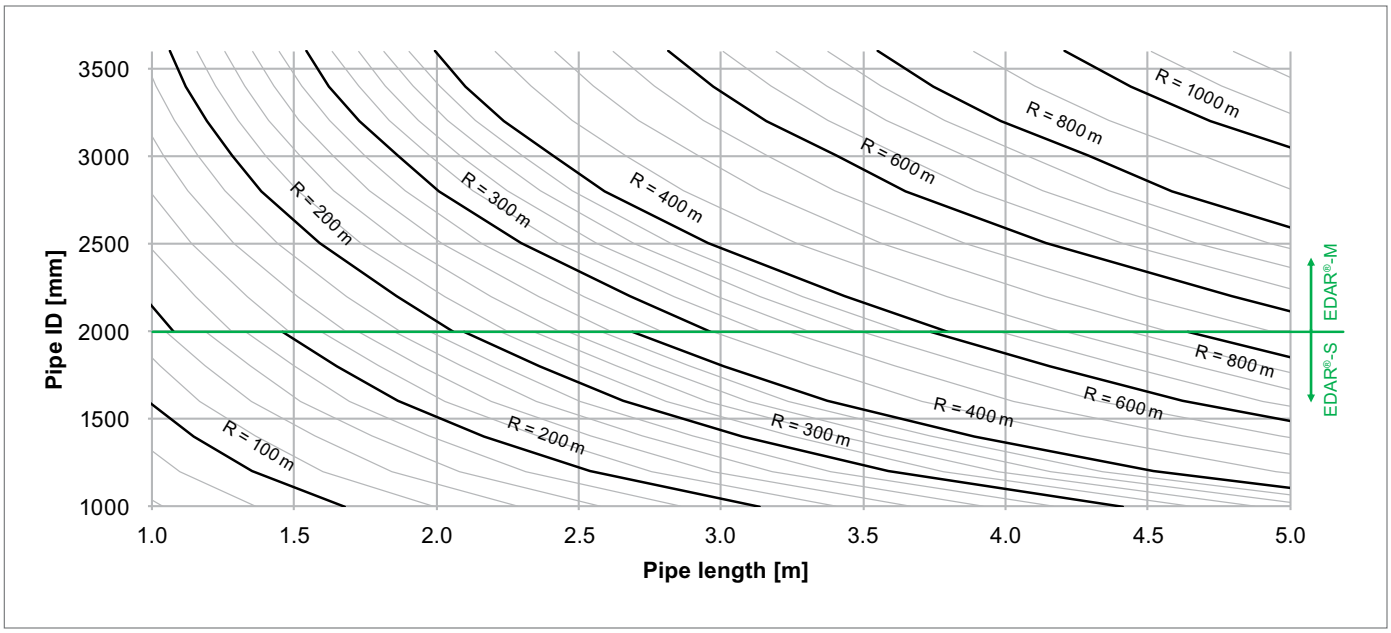
After the jacking operation, the EDAR® can basically be left in the pipe joint without taking any further action. In the case where the EDAR® is used / activated as an internal joint closing or secondary inner seal, the work steps described on page 55 must be performed.

Monitoring of Jacking Process / MSS

Pipe lines equipped with the EDAR® can be supported by MMS, whereby the algorithm described by the Code DWA-A 161 is used if JCPipe® applied. For longer and more demanding alignment, the use of MSS during the jacking process is recommended for quality assurance. However, as a result of its simple and robust design, the EDAR® can also be used without monitoring system for short and / or simple drives.

Range of application of EDAR® with MSS monitoring

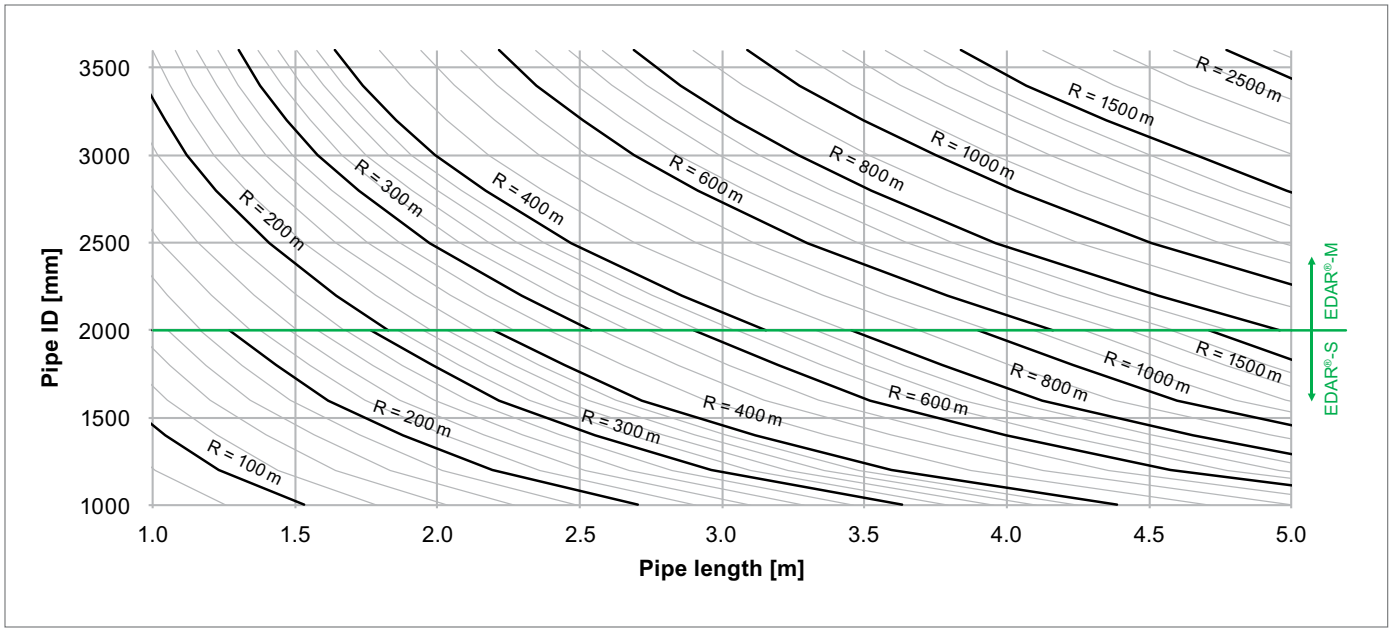
(reduced steering movements according to DWA-A 161, 10.3)



MOUNTING OF THE EDAR®

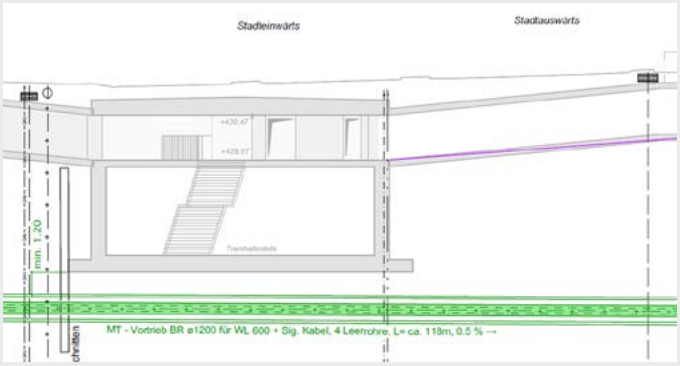
Range of application of EDAR® without monitoring

(taking account of steering movements according to DWA-A 161, 10.3)



Microtunnel with EDAR®-pressure transfer ring below tramlines and motorway

In the east of the city of Zürich in Switzerland, the motorway built in the 1980s is being enclosed with a cut-and-cover tunnel. As a result of this cut-and-cover tunnel, a utility structure will arise, unique in Switzerland, almost a kilometre long and around 30 metres wide, that will join together the settlement area again that had been split by the motorway. The green and open space created on the roof of the structure, accessible by stairs, ramps and lifts, is intended to provide a meeting and recreation zone for the population. Due to the foundations additionally required for the cut-and-cover tunnel, an existing water pipe DN 600 has to be relocated. As this new pipe line has to cross under the motorway as well as the tram line and tram stop under the motorway, it was decided to construct a casing pipe using microtunnelling to slipline the new water line into this casing pipe afterwards. A pipe with nominal width of DN 1200 mm was selected for the microtunnel. The challenge with this project is that the microtunnel is situated only 1.20 m under the existing tram stop. For the tunnelling, the EDAR®-S pressure transfer ring and the real-time monitoring system from Jackcontrol AG were selected.



LONGITUDINAL PROFILE

AT A GLANCE	
Project name	N01/40, Zürich Unterstrass – Zürich Ost, Einhausung Schwamendingen Los V, Abschnitt Schörli, Unterquerung WVZ
Location	Zürich, Switzerland
Purpose	Casing pipe for water main and additional utilities
Time of completion	2017
Specialties	▪ Crossing under tram tracks and motorway above that ▪ Tunnelling during operation of tram and road traffic ▪ First use of EDAR®-S ▪ First use of EDAR® at Jackcontrol AG
Total length	121 m
DN/ID	1200 mm
OD	1490 mm
Alignment	Straight line
Minimum curve radius	Straight line
Pipe material	Reinforced concrete
Pipe length	3 m
Max. overburden	12 m
Geology and groundwater	At the level of the pipe jacking, sandy/silty lake sediments
Pressure transfer medium	EDAR®-S
TBM	Herrenknecht AVN 1200
Owner/Client	Bundesamt für Strassen ASTRA, Filiale Winterthur
Consultant/Designer	INGE K12plus
Tunnelling company	Braumann Tiefbau AG, Switzerland

5.4 CEMENT PASTE INJECTION JCGrout

The leak tightness of the pipe joints for jacking pipes must usually be maintained over the entire service life of the pipeline. Primarily, the dimensioning and correct installation of the steel collar and the wedge-shaped elastomer seal play an important role. The entire inner joint seal is also of great importance. Particularly in the case of liquid-carrying pipelines, liquid can penetrate from the interior of the pipe to the steel collar without a joint seal and thus accelerate their corrosion. Furthermore, a joint closing is often regarded as a secondary seal which can prevent or at least minimise the ingress of groundwater into the pipe interior in the event of failure of the primary seal.

For all types of joint seals (joint tape, grouting of the joint gap, knock-in profile, etc.) the annular cavity/hollow space between the pipe face, the steel collar and the pressure transfer medium remains. Even if the primary seal is intact and the rubber seal is in place, moisture will sooner or later cause corrosion of the steel collar.

In order to prevent corrosion damage to the steel collar and to subsequently improve the leak tightness of the pipe joint, Jackcontrol AG has developed a process in which the annular cavity in the pipe joint is filled with cementous paste and thus at the same time the steel collar is sustainably protected against corrosion: the **JCGrout** cement paste injection.

Requirements for the JCGrout cement paste injection

Filling the ring space with cement paste requires internal shuttering; this function is performed by the Hydraulic Joint. The Hydraulic Joint can be used as an internal joint seal, see also the illustration below, except in the area of the cavity/fittings. The Hydraulic Joint is characterised by the fact that no joint gaping occurs when the joint gap widths vary (e.g. when jacking around curves). In the case of straight alignments and/or large curve radii, the EDAR® can also take over the function of the inner shuttering as well as the internal joint seal.

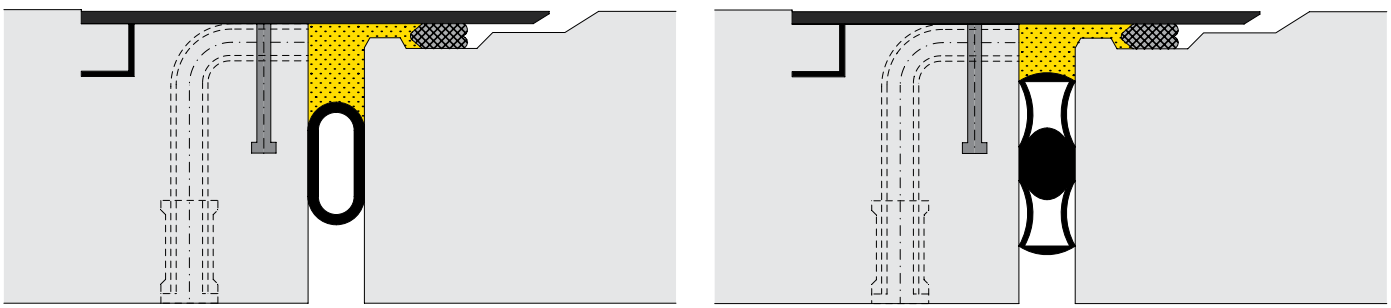
Furthermore, a filling and a venting nozzle is required on each pipe for the ring space filling. The venting nozzle is normally positioned on the pipe crown, the filling nozzles on the lower part of the pipe cross section, preferably close to the bottom of the pipe.

Filling material

The following criteria are relevant for the material injected with JCGrout:

- Simple handling and processing
- Low-cost (depending on the pipe diameter, up to more than 20 litres can be filled per joint)
- Resistance to waste water/sewage
- Passivating or corrosion-inhibiting effect on the steel guide ring
- Adhesive property towards the concrete pipe surfaces
- Penetration capacity in small cavities and cannulas on the concrete surface
- Durability

These criteria are best met by properly mixed cement suspension, also called cement milk or cement paste. Cracking within and/or between the hardened cement suspension and the pipe end faces as a result of shrinkage of the cement suspension or possible movements of the pipeline in the soil cannot be completely prevented even if a shrinkage-minimised formulation is used for the cement suspension, even if the ring space filling is carried out after completion of the jacking work and after the ring gap has been filled on the soil side. However, this is not relevant for the sealing effect, because the sealing effect takes place by the cement suspension penetrating into the small-volume pores and cannulas between the pipe concrete and the pressure transfer ring. This is not affected by shrinkage cracks due to the small volume. Furthermore, their sealing effect is not impaired by any external movements of the pipeline after the outer ring space has been filled, as the outer surfaces of the Hydraulic Joint or the EDAR® can compensate for these movements; the permanent elasticity is thus ensured by the elastic outer skin of the pressure transfer ring. The maintenance of an alkaline environment



SECTION THROUGH A JACKING PIPE WITH JCGrout (ON THE LEFT WITH HYDRAULIC JOINT, ON THE RIGHT WITH EDAR®)

or high pH value is also not impaired by individual shrinkage cracks.

The following are taken into account in the formulation of the cement suspension:

- Use of a fine-grained cement, especially suitable for injections and shrinkage-minimised curing.
- Selection of a water/cement ratio at which almost the entire amount of water in the curing process of the cement is absorbed by the cement and thus no excess water is produced or no shrinkage occurs in the cement suspension.
- Addition of additives for slower uring of cement and improved viscosity during processing.

Description and function of the ring space filling

The ready-mixed cement suspension is injected into the ring space through the filling nozzle, initially flows in this towards the lower half of the pipe and gradually fills the ring space from below on both sides up to the crown, whereby the air displaced from the ring gap can escape through the venting nozzle. When the ring space is completely filled, excess cement suspension flows out of the venting nozzle. This is the indication that the ring space is completely filled.

If the ring space is partially or completely filled with liquid or water, the liquid is displaced upwards by the cement suspension in the ring space during the filling process and pressed out of the venting nozzle as well. In this case, the filling must be continued until only pure cement suspension is discharged from the venting nozzle. The removal of unwanted water from a joint is therefore a simple matter or a positive side effect with the described ring space filling.

MULTIFUNCTIONAL, SELF-SUFFICIENT TUNNEL VEHICLE CT ROVER, CONSISTING OF TWO COMPONENT VEHICLES

CT ROVER IN TUNNEL DN 3000 MM

The filling speed is selected and adjusted so that the cement suspension can flow into each cavity during filling and thus complete filling of the ring space is achieved. This was investigated in detail within the scope of an in-house series of tests using a pipe and joint testing device and could be verified.

Ring space filling with Compact Tunnel Rover (CT Rover)

A specially designed tunnel vehicle, the Compact Tunnel Rover **(CT Rover)**, has been developed to perform the JCGrout injections.

The key features of the CT Rover are:

- Pipe diameter application range: DN 1200 mm to DN 3500 mm
- Crew of two
- Autonomous (battery) operation for at least 5 hours
- On-board lighting
- High safety standard (various limit switch enables required for movement, self-rescue of the crew using the accompanying mobile stretcher)
- Simple and efficient handling
- Comfortable workplace even in confined spaces with DN 1200 mm

CT ROVER WITH CEMENT TANK / MIXER AND INJECTION PUMP AT THE TUNNEL ENTRANCE

INSERTION OF THE SHUTTERING STRIP INTO THE CAVITY AREA IN PIPE DN 1200 MM

- Easy to dismantle and (air) transportable on Euro pallets

In summary, the CT Rover consists of two component vehicles connected via a drawbar, whereby one vehicle mainly contains the batteries and is used as a work bench, while the cement suspension and the injection pump are carried along in the other vehicle. Both component vehicles can also move independently of each other in the tunnel and are equipped with comfortable seats or work surfaces for the operating crew.

JCGrout in practice

Jackcontrol AG has already used JCGrout for several dozen drives. The course of an injection campaign is usually as follows:

Work preparation

A single-loop Hydraulic Joint is usually used. Therefore, in the area where the two end fittings of the joint meet, a recess unit is installed before the filling. This ensures that the ring space to be filled is closed off around the entire circumference of the pipe and is completely filled. Also included in the preparation work is the mounting in of the filling and venting nozzles; this work is carried out safely and efficiently using the CT Rover.

Ring space filling

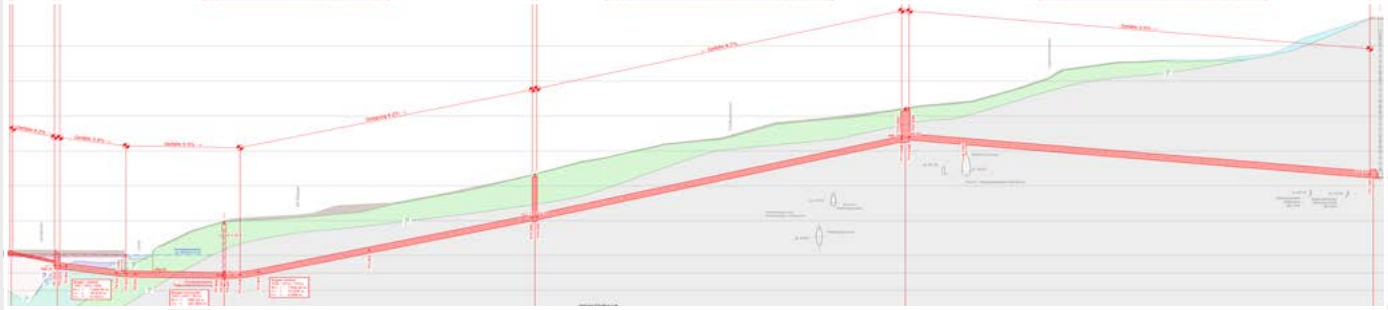
The actual filling can be started after completion of the preparation work. After mixing outside the tunnel, the finished cement suspension is filled into the tank of the CT Rover at the tunnel entrance and then driven from joint to joint to fill the ring space. During this process, the cement suspension is kept in constant motion by a mixer in order to maintain the processing properties. Premature curing of the cement suspension is prevented by using a suitable additive.

JCGrout RING SPACE FILLING WITH THE CT ROVER

Completion work

After the cement suspension has hardened, all filling and venting nozzles as well as the shuttering must be removed again and the sealing plugs screwed in. This is again done safely and quickly with the CT Rover.

District heating for Zurich West
Microtunnelling with JCGrout



In order to maintain district heating in the western part of the City of Zurich after the decommissioning of the Josefstrasse waste incineration plant, a 6 km long connection pipe line to the Hagenholz waste incineration plant has been constructed. About 2.3 km of this pipe line is installed in new tunnels constructed using the microtunnelling method. These connection tunnels were constructed in three drives, twice with a nominal diameter of 3000 mm and once with a nominal diameter of 3200 mm.

Hydraulic Joints from Jackcontrol AG were used for all three drives. The annular hollow space between the Hydraulic Joint and the steel collar were also filled using cement paste injections in all three drives as well. This improved the leak tightness of the pipe connection and ensured the corrosion protection of the steel collar. In addition, two other smaller tunnels with a nominal diameter of 1200 mm were constructed, which run in parallel and have a distance of only 32 cm between the outer sides of the pipes.

JCGrout CEMENT PASTE INJECTION:
CTROVER IN THE TUNNEL FOR GROUTING WORKS

AT A GLANCE	
Project name	ERZ Zürich-West
Location	City of Zurich, Switzerland
Use	Pipeline tunnels for district heating pipelines
Executed	2019/2020
Specialties	▪ Retraction of tunnelling machine for more than 800 m ▪ Tunnelling underground cavern Overburden > 80 m ▪ Limmat river crossing ▪ Breakthrough of two TBM almost at the same time in launch shaft
Total length	863 + 666 + 840 = 2369 m
Inner diameter	1200/3000/3200 mm
Outer diameter	1490/3600/3800 mm
Alignment	4 drives, straight 1 drive, 3D-curve
Min. curve radius	R_{comb} = 570 m
Pipe material	Reinforced concrete
Pipe length	3.00/2.80/4.50 m
Max. overburden	86 m
Geology	Gravel, moraine, molasse
Hydraulic Joint	DN 1200 straight: JC132 double loops DN 3000/3200: JC250 double loops
TBM	Herrenknecht AVN2500
Owner/Client	Entsorgung und Recycling Zürich
Planner/site management	INGE Energie Consisting of Emch+Berger AG and Locher Ingenieure AG
Tunnelling companies	Implenia Schweiz AG, Zürich Sonntag Baugesellschaft, Dörth
Pipe manufacturer	HABA Beton

5.5 INTERNAL JOINT SEAL JCFlex

Description and range of application

As the Hydraulic Joint cannot be implemented as a closed ring, there is an interruption or opening between the two ends of the Hydraulic Joint (fittings). In tunnels with required internal joint seal, the Hydraulic Joint can basically perform this function, except in the area of the cavity where the fittings are located. Jackcontrol AG provides JCFlex, a joint sealant, to fill this “gap”. JCFlex basically consists of a suitable sealing compound based on silane-modified polymers. JCFlex can be used for internal cavities. However, JCFlex is not used for open (external) cavities; in this case, the cement paste injection JCGrout is suitable, see also 5.4.

JCFlex OVERVIEW

Requirements

After the jacking process, all Hydraulic Joints are first drained. This is done by opening the ball valves of the Hydraulic Joints and compressing them by pushing on the pipeline, thus allowing the fluid to escape. This results in minimal gap widths between the pipes and each pipe thus reaches its final position. In a further step, the filling lines of the Hydraulic Joints must be removed (cut off).

Work steps

The application of JCFlex involves the following two steps:

1. A suitable foam cube fills the hollow space in the cavity between the fittings. This prevents unwanted penetration of the sealing compound into the remaining cavity area and thus unnecessarily high consumption of sealing compound.
2. The sealing compound is applied evenly and without air inclusions into the joint gap in the area of the two fittings using a cartridge press. The sealing compound is smoothed out with a spatula and levelled to the Hydraulic Joint on both sides.

VIEW OF CAVITY AREA FOR HYDRAULIC JOINT TREATED WITH JCFlex

Material properties of the sealing compound

- One-component, paste-like adhesive and sealing compound based on silane-modified polymers, which, is characterized by high chemical and mechanical resistance.
- Can also be applied on moist surface.
- Excellent adhesion properties to concrete, steel and outer skin of the Hydraulic Joint.

Advantages

- Less expensive option of a joint seal compared to cement paste injection.
- Very low mechanical stress as a result of application after jacking process.
- Can also be used on varying joint gap widths (curve advance).
- Can be carried out quickly and flexibly with simple equipment.

6 **Quality assurance** in pipe jacking / microtunnelling

6.1 THE OPTIMUM MONITORING SYSTEM FOR EVERY MICROTUNNEL

Adapted to the project requirements and the pipe materials used, Jackcontrol AG provides the optimum monitoring system for every pipe jacking or microtunnelling project. Thanks to a modular design, comprehensive real-time monitoring of the pipe structure during the jacking process is possible for all commonly used combinations of jacking pipe and pressure transfer media (see pages 16 / 17). Within the same drive, different pressure transfer media can also be used (so-called hybrid method). For the software set-up, all current standards used in pipe jacking can be taken into account, e.g. DWA-A 125 and 161, EN 1916, SIA 195, CPAA, PJA, etc.

The pipe design can be carried out by Jackcontrol AG, but pipe designs of third parties (pipe manufacturers, project designers, etc.) can also be integrated and adopted.

6.2 **BASICS**

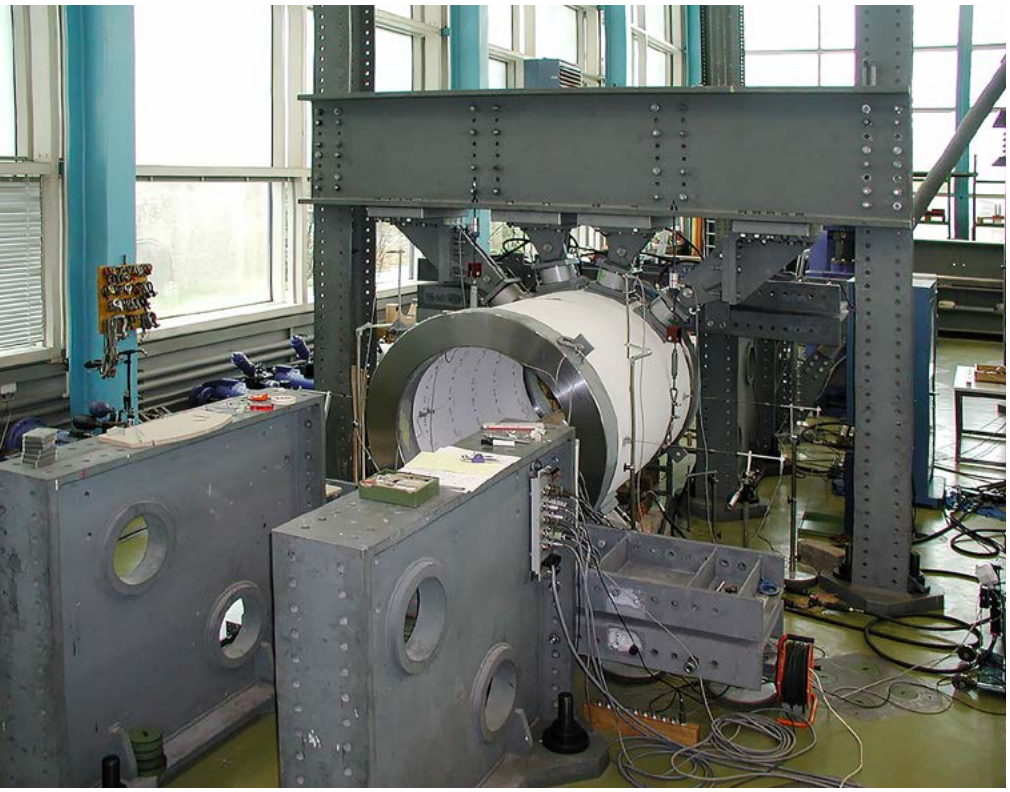
With pipe jacking, the jacking pipes are subject to additional loads during the construction phase. Jacking forces acting axially push the pipes behind the tunnelling machine through the soil. These forces have to be transferred from pipe to pipe safely by using suitable pressure transfer media. The Jackcontrol MSS monitoring system measures the jacking forces in real-time together with the joint articulation angle and protects the pipes against overload and damage thanks to safety margins and timely alarms.

MSS is based on research conducted in Switzerland at ETH Zürich at the Institut für Baustatik und Konstruktion (Institute of Structural Engineering) under the leadership of Prof. Dr. Peter Marti. Using large-scale test series on jacking pipes and theoretical considerations, the load-bearing and deformation behaviour as well as the decisive failure mechanisms for eccentrically loaded reinforced concrete pipes were investigated. The research showed that usually used pressure transfer rings made of timber materials result in large stresses in the pipe walls, mainly during planned as well as unforeseen cornering and steering movements, and thus present a considerable potential for damage. With the Hydraulic Joint, the eccentricity of the jacking force with respect to the pipe axis is reduced in the case of non-parallel pipe faces, i.e. particularly in curves, and this thus significantly reduces the stress on the pipes orthogonal to their axis. At the same time, the determination of the stress state in the joints is made possible. Based on this knowledge, the first Jackcontrol real-time monitoring system was developed, in its original form designed for use with the Hydraulic Joint.

With all pressure transfer media used in pipe jacking, including the Hydraulic Joint, the transfer of jacking forces between the jacking pipes is eccentric to the pipe axis in the case of an offset of the pipe faces to each other. However, much smaller eccentricities result when the Hydraulic Joint is used compared to when pressure transfer rings (PTR) made of timber are used (see graphs on page 46).

For reasons of equilibrium, additional forces acting transversely to the pipe axis, so-called lateral bedding forces (B) result from the eccentric loading of the pipes. These are overlaid on the continual loadings on the pipes (soil pressure, water pressure, traffic loads, etc.) during the jacking process. Depending on the orientation of the joint articulation angle, the lateral bedding forces can act on the jacking pipes in all radial directions, as can be seen in the two graphics on page 46.

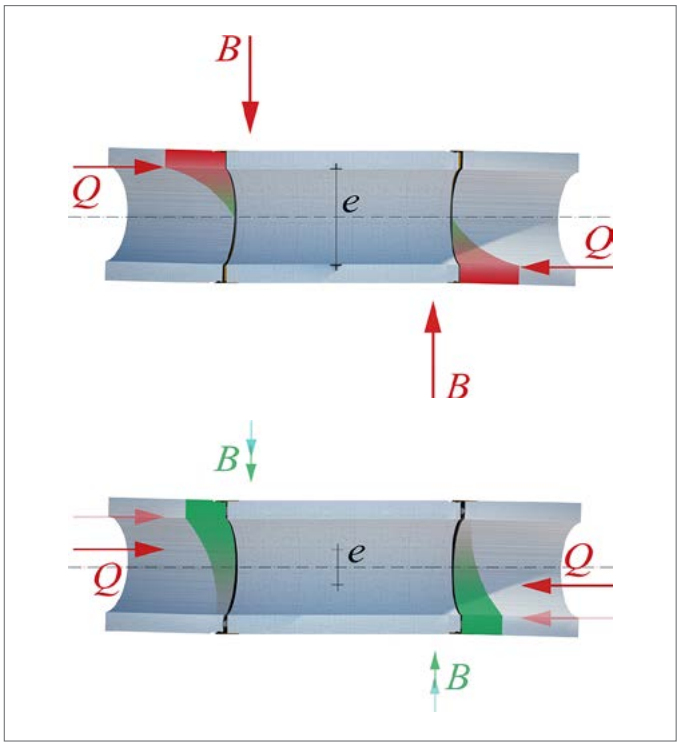
Depending on the spatial orientation of the lateral bedding forces, the mechanical properties of the jacking pipes and the nature of the ground, the lateral bedding forces reach a maximum admissible level at which the structural safety of the jacking pipes is still ensured. From this, a



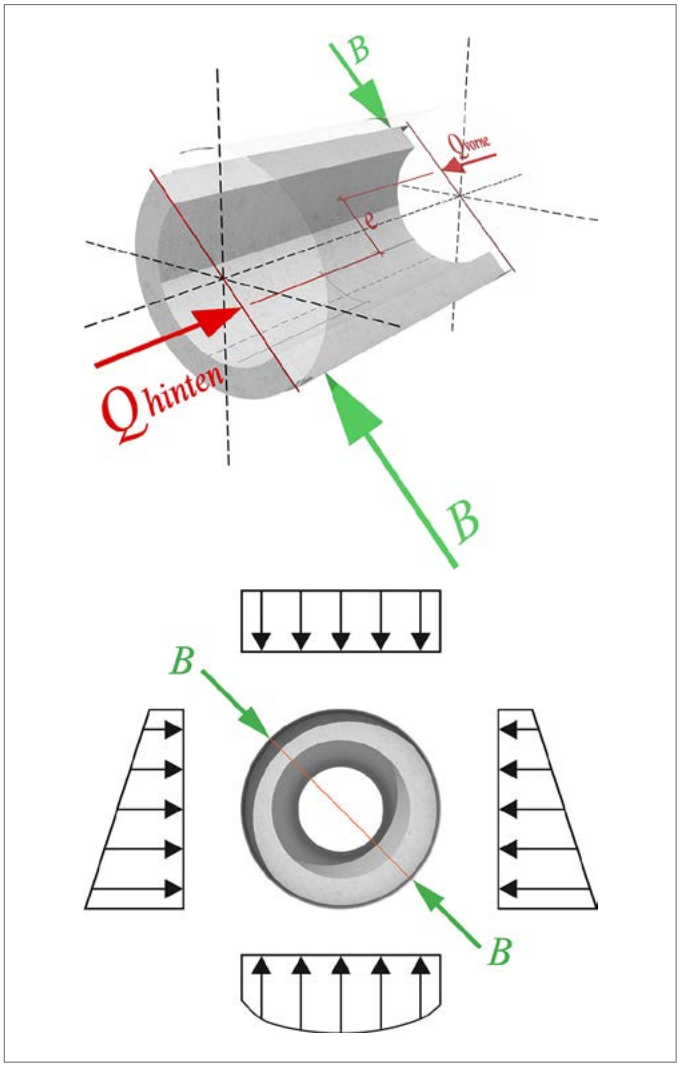
LARGE-SCALE TESTS ON REINFORCED CONCRETE JACKING PIPES AT ETH ZÜRICH (2003 / 04)

FAILURE MECHANISMS ON JACKING PIPES

LAUNCH SHAFT



COMPARISON OF PIPE ECCENTRICITY FOR WOODEN RING (TOP) AND HYDRAULIC JOINT (BOTTOM)



FORCES DURING JACKING PROCESS

range arises for every project in which the jacking force Q and its eccentricity e can be without the jacking pipe being damaged. This is represented by the green area in the example at the top on page 63, a so-called limit value diagram.

It can be seen from the diagram (at the top on page 62) that with increasing eccentricity e, the jacking force Q has to be reduced in order to remain in the green area. There is a danger of leaving this when making abrupt steering movements, tight curve radii, etc.

The operation of the Jackcontrol monitoring system is such that, based on the effective measured joint gap widths and pressures in the Hydraulic Joint, for every pipe every 3 seconds, the pair of values $[Q;e]$ is automatically determined and entered into the limit value diagram appropriate for the position and stress direction. Based on the e value, the maximum admissible jacking force Q_{adm} is thus determined for each pipe and compared to the effectively prevailing jacking force Q_{eff}. As soon as Q_{eff} exceeds the determined admissible value Q_{adm} , the site team is automatically alerted by MSS and the problem brought to their notice. Thanks to the implementation of safety margins / factors, this warning occurs before the actual occurrence of damage to the pipes, which is the decisive safety mechanism of the monitoring system, and which ensures compliance with the quality criteria required by the project.

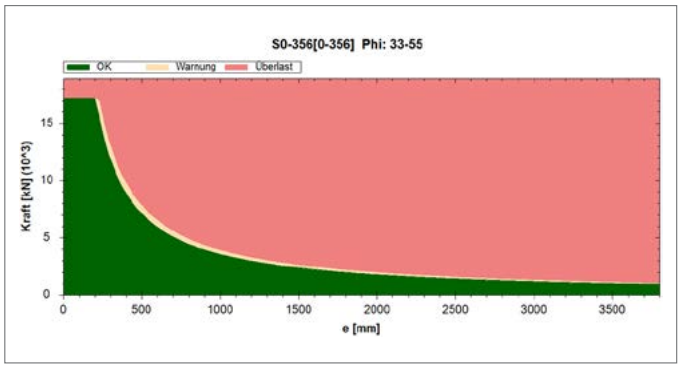
The comparison of actual jacking force to admissible jacking force is presented to the TBM operator in real-time on the MSS Chicago Screen, so that the operator has an overview at all times of the development of the jacking forces and the available reserves.

Selected pipe joints in the pipeline are continuously measured with a sensor unit and the measured values allocated to the chainage. In this way, for every pipe, a (identical) joint angle sequence along the chainage is determined. This joint angle progression is updated each time a new sensor unit is passed. The sensor units each consist of three distance sensors for measuring the joint gap width, and a pressure sensor for determining the pressure in the Hydraulic Joint. At the location of the sensor unit, this allows a reliable determination of the size of the resulting jacking force and its point of attack in the pipe cross section as well as the determination of the joint articulation angle. With a linear interpolation of the jacking forces between two sensor units, the jacking force in every pipe joint can be determined, without the need to measure every joint.

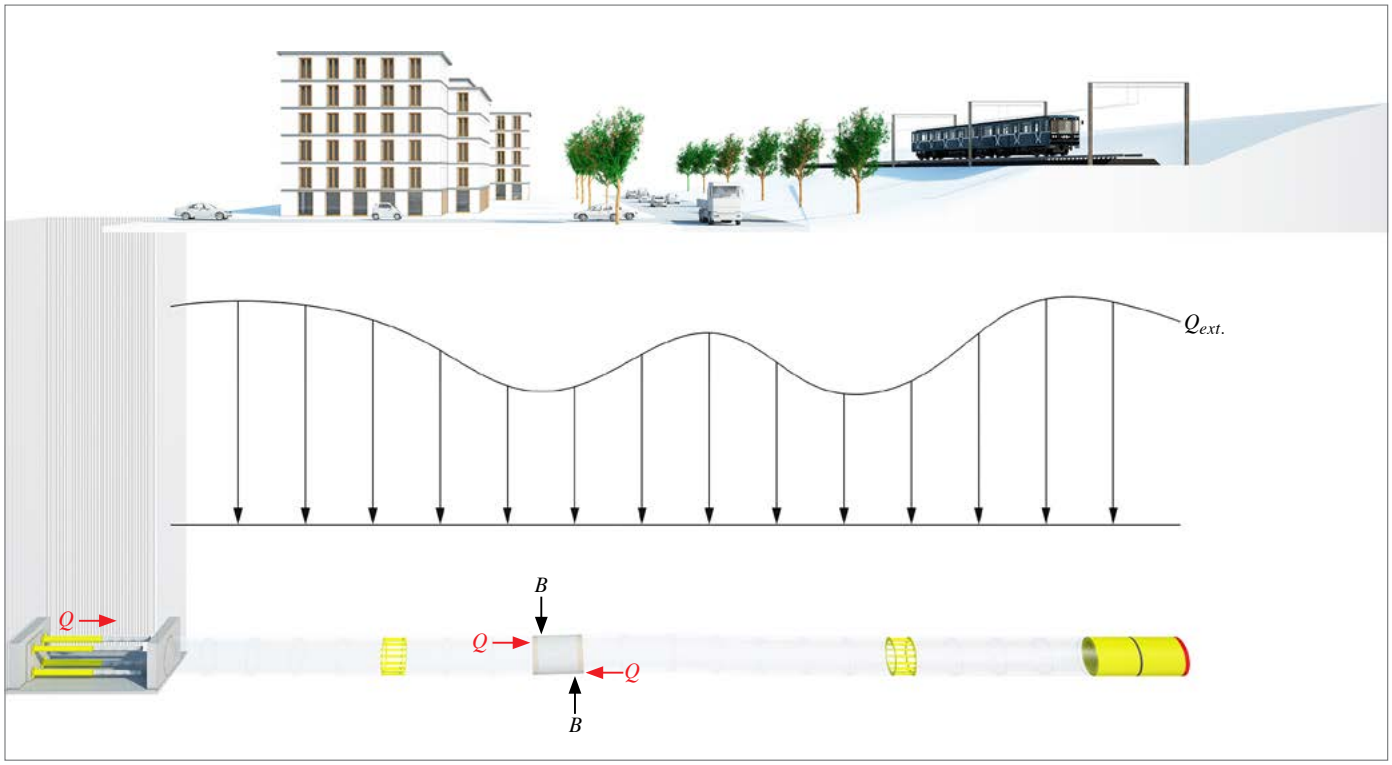
For the calculation of the limit value diagrams, the jacking distance is divided project specifically into different geological sectors. The calculation of the limit value diagrams is carried out according to the methods and verifications of generally accepted codes of practice structural design as described in standards and literature for determination of the load resistances of the pipes. In the process, the following structural safety and serviceability criteria are taken into account:

- Crack formation
- Concrete spalling
- Bending load
- Shearing stress
- Fatigue strength
- Operating pressure of the Hydraulic Joint

Additional criteria can also be taken into account or individually excluded (e.g. crack formation on casing pipe with a short service life) for specific projects.



EXAMPLE LIMIT VALUE DIAGRAM HYDRAULIC JOINT



OVERLAY OF THE LATERAL BEDDING FORCES RESULTING FROM THE JACKING PROCESS WITH THE ACTIONS FROM THE GROUND

6.3 SOFTWARE

Visualisation of the process data and analyses

The measured process value analysis is carried out on the MSS site computer independently of the presence of an Internet connection, and the results are displayed clearly and graphically in real-time on the touchscreen. The most important drive data are summarised on the Chicago Screen. The most important graphic is the presentation of the current jacking force development, which is compared in the same graphic with the length of the pipeline and the development of the admissible jacking forces. See also screenshot below. Underneath is the pipe sequence with pipe numbering together with the length of the pipeline in the soil / chainage.

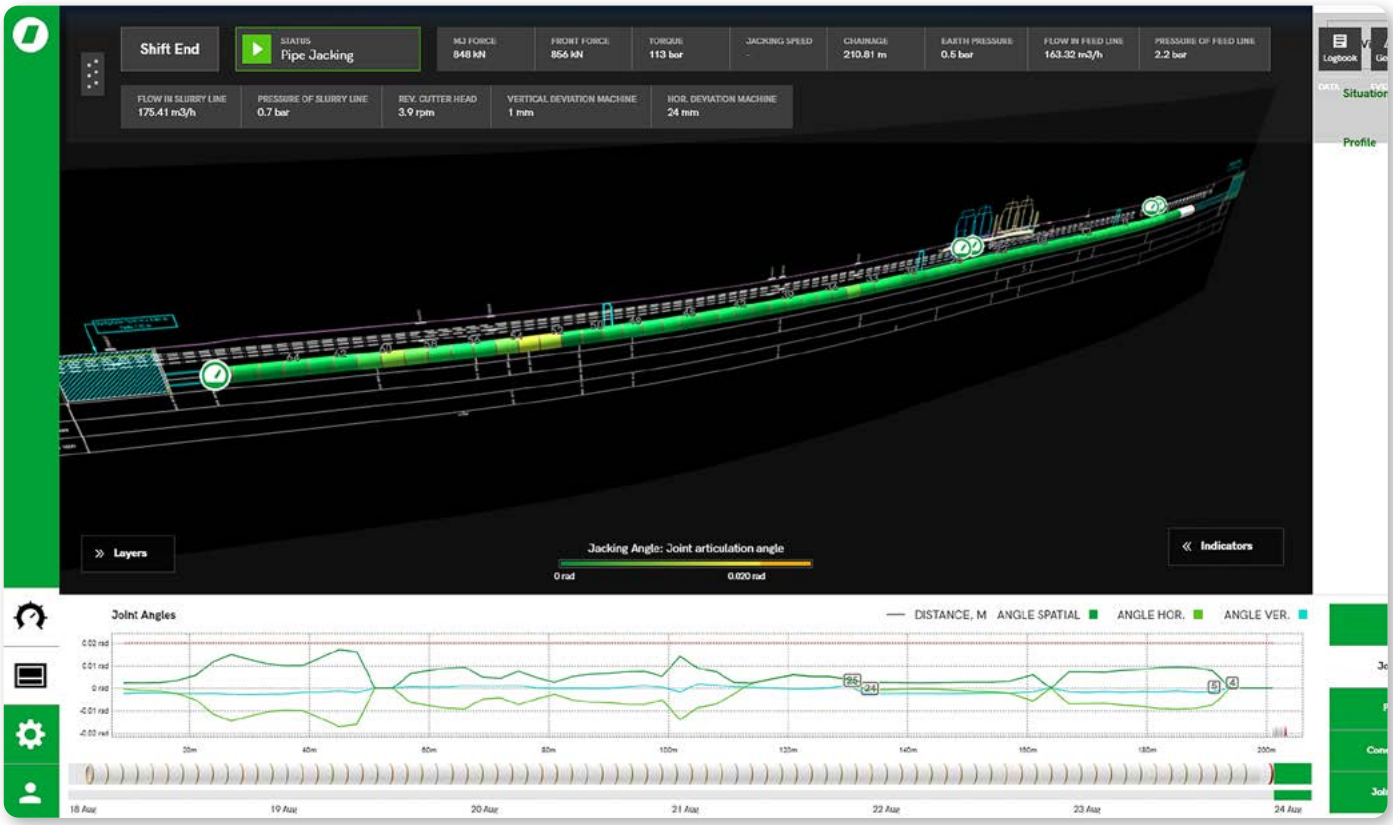
Furthermore, numerous other graphics with analysis values from the microtunnel process can also be displayed on the screen, such as the development of the maximum occurring jacking forces for each pipe, the pipe eccentricity, the joint angle spatially / absolutely, as well as the orientation of the lateral bedding forces divided into vertical and horizontal components and more.

Thanks to various zoom and display functions, and the possibility of combined display of multiple graphics, the system user can clearly display the information mix ideally tailored to his current microtunnel situation.

In addition, using buttons and pop-up windows, much valuable information about the microtunneling process can be called up, such as pipe data, measured values of the individual sensors and function status of the individual hardware components. Thanks to the touchscreen functionality, the operation of the system and the (little necessary) data inputs can be done without a mouse and keyboard in an intuitive manner related to the site.

Visualisation of situation and longitudinal profile

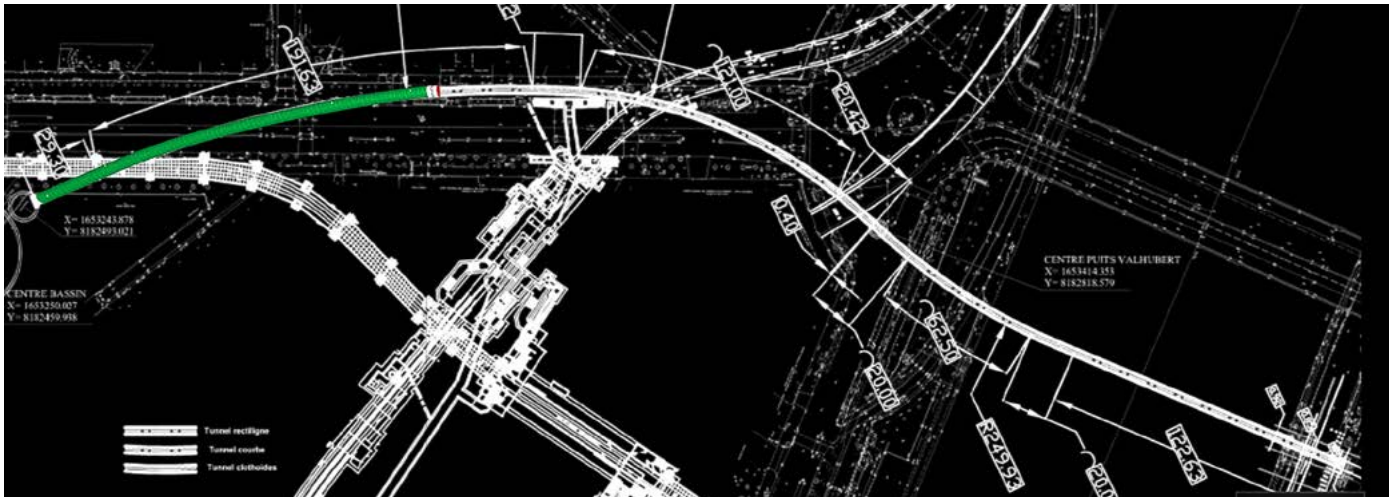
For fast orientation in the project and terrain, the project plans implemented in the software are useful, which generally include the situation plan and longitudinal profile as well as a 3D display. The currently driven pipes are projected into these project plans in real time. The actual position of the tunnelling machine, individual interjacks or pipes are thus visible at any time. Any perspective can be set on the touchscreen with just a few finger taps. With a simple double tap on a pipe, an additional window opens which shows parameters and measured values of the pipe and the respective joint.



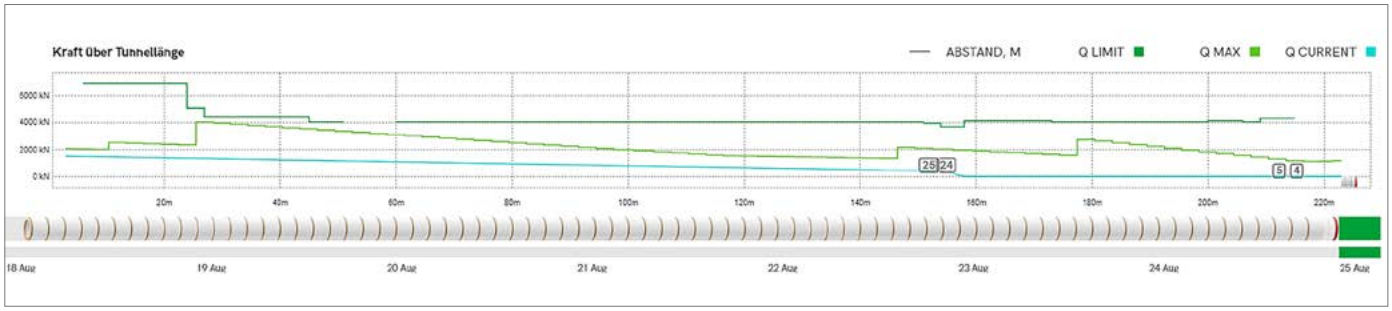
CHICAGO SCREEN WITH DEVELOPMENT OF EXISTING AND ADMISSIBLE JACKING FORCES

PIPE AND JOINT INFORMATION

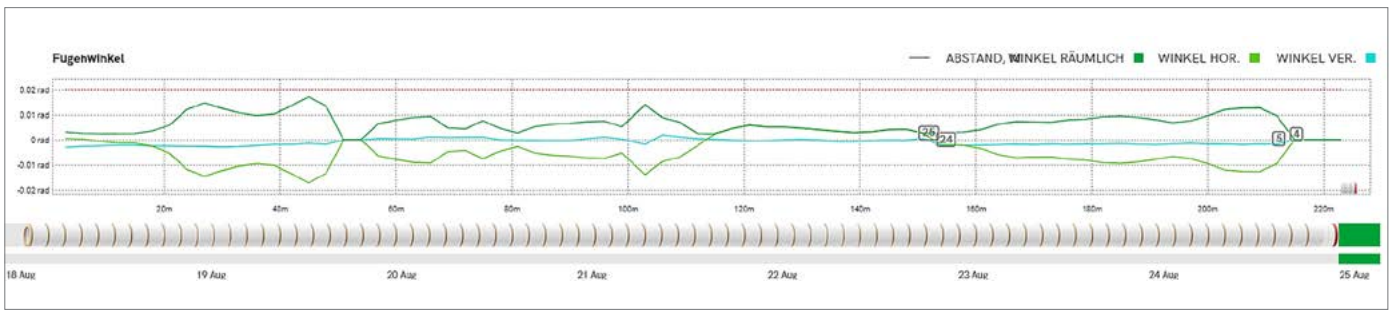
The automatic registration of the construction progress makes it intuitively visible where the tunnelling machine is currently located, which provides very valuable knowledge with regard to existing infrastructure in the ground (such as utility lines, foundations, etc.) and the recognition of risks in good time. It is also possible to see in which soil layers the drilling equipment and the pipes are currently positioned. Based on a comparison between the excavated soil and the geological projection, the latter can be efficiently calibrated and adjusted if necessary.



VISUALISATION OF SITUATION AND DRIVEN PIPELINE



DEVELOPMENT OF THE EXISTING, ADMISSIBLE AND MAXIMUM OCCURRING JACKING FORCES

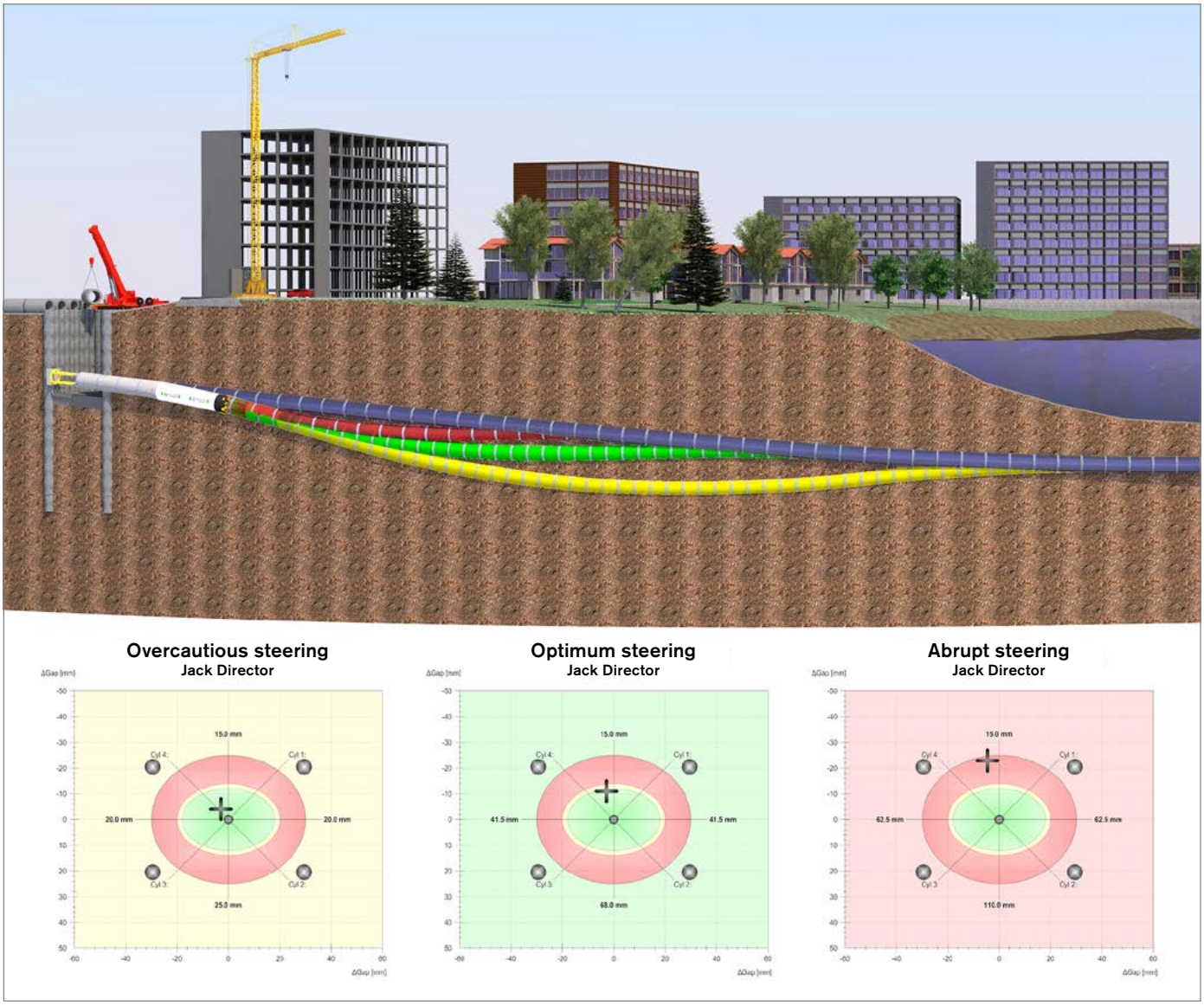


DEVELOPMENT OF THE MEASURED GAPS BETWEEN THE PIPES

6.4 JACK DIRECTOR®

The TBM operator usually instinctively pursues the goal of guiding the TBM along the planned alignment as closely as possible. But it is important the same to be able to apply the maximum admissible jacking forces during the whole jacking operation. Large angular movements in the pipeline must be avoided, because they result in reductions of the admissible jacking forces. But how should the TBM operator control the drilling equipment so that excessive articulation changes and thus reduced admissible jacking forces can be avoided? The Jack Director® software module provides valuable support here: Using the measured movements and positions of the steering cylinders of the TBM, the Jack Director® software evaluates the steering movements of the TBM and compares them with the effective measured joint articulation angles on the subsequent jacking pipes and thus the admissible jacking forces. From this "learning curve" the Jack Director® software gains the knowledge of the range in which future steering movements of the TBM can be done so that no reductions in the admissible jacking forces are needed, see also the image below.

If the current steering angle of the TBM represented by the crosshairs is in the green elliptical area of the graphical display, the consecutive jacking pipes can be jacked without any reduction of the admissible jacking forces being necessary. If a course correction has to be made to maintain the alignment, the steering angle can be changed up to the boundary of the green area. The optimum course correction while maintaining the maximum possible jacking forces is at that point. If the crosshairs move outside the green area, a reduction of the admissible jacking force by the monitoring system must be expected or even damage to the pipes if the jacking force is not reduced. The Jack Director® software supports the TBM operator in this way to retain the drilling control and admissible jacking forces in optimal balance.



JACK DIRECTOR®

6.5 SUPPORT (REMOTE CONTROL, DATA ANALYSIS, FAULT CLEARANCE, ADVICE)

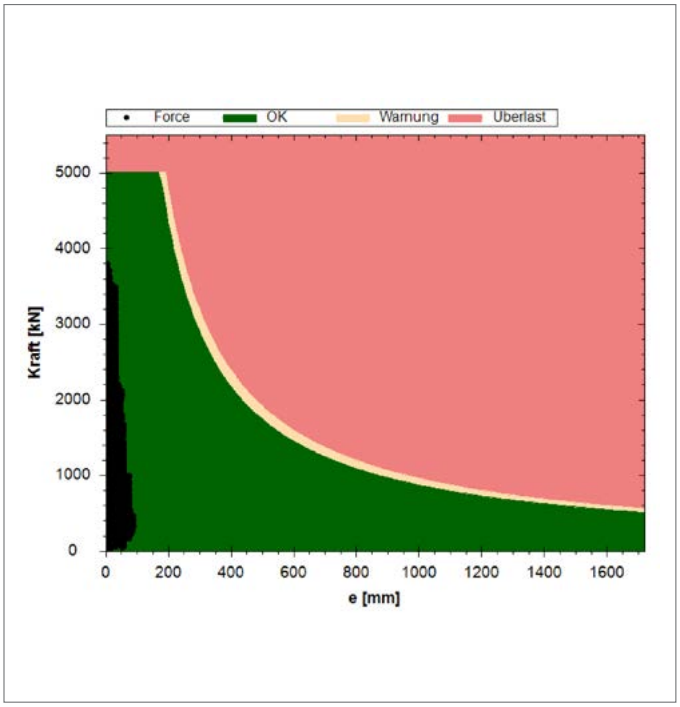
The measurement data and evaluations of the site computer are made available on the Jackcontrol website for third parties involved in the project. This makes efficient and multifaceted support possible. Authorised persons with appropriate log-in credentials can follow the processes on the jobsite via the www.jackcontrol.com website.

From the Jackcontrol AG operations centre, remote control of the site computer can be established and thus direct, fast and efficient support for the jobsite can be provided. During the jacking operation, Jackcontrol produces a status report of the construction progress and makes contact with the jobsite if the analyses carried out show unfavourable developments and measures need to be taken. Questions by the jobsite personnel about measurement data and graphics are thus analysed and answered by Jackcontrol employees. Any problems and faults are mostly resolved using this channel efficiently and quickly.

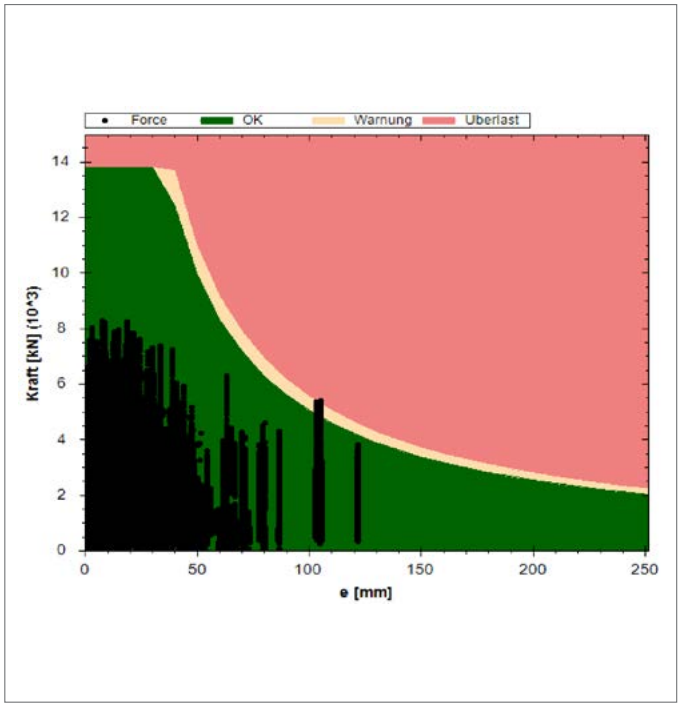
6.6 DOCUMENTATION OF THE JACKING PROCESS

After the end of the drive, the measured values and evaluated data on the jacking process are summarised in a final report. All important points of the jacking process are also recorded in it in text form.

The final report shows in particular the loads on the individual pipes caused by the jacking forces and shows whether the jacking forces remained within the admissible range of the limit value diagrams during the entire jacking or whether there were any breaches. For the evaluation of all jacking forces that occurred during construction, the maximum force curve of the pipes is considered and, in the case of the Hydraulic Joint, the forces of all pipes are displayed in the limit value diagrams. In the case of infringements of limit values, the final report shows at what point / time and for which pipes these have occurred, which design criteria are affected and what damage to the pipes must potentially be expected.



EXAMPLE EVALUATION LIMIT VALUE DIAGRAM



LIMIT VALUE DIAGRAM WITH BREACH OF THE ADMISSIBLE JACKING FORCE

Eliminating shafts
and optimising construction schedule in Washington DC

Bradshaw Construction Corp. carried out the tunneling work for the sewer rehabilitation project in Oregon Avenue NW for DC Water. This included creating roughly 1311 m of PVC sewer pipes using a jacket pipe produced microtunneling technique on a total length of 823 m. The western section along Bingham Drive NW originally consisted of four short, straight microtunnels that had to stay within the road corridor. Two of the shafts would have had to be built in the middle of the road and thus blocked the access to the eastern, open section, which would have made it impossible to work on both at the same time. Jackcontrol redesigned the alignment by implementing an S-curve and combining three tunnels into one in order to eliminate these two shafts. The client approved Bradshaw for this value engineering proposal including changing the steel jacket pipe to a reinforced concrete jacket pipe in order to be able to drill the curve. The microtunnel work started on January 9 and was finished on February 5. The jacking forces and force eccentricities measured and controlled by the real-time monitoring system of Jackcontrol were low and the serviceability and structural safety of the jacking pipes were never compromised. “I had expected much higher jacking forces in the curve, but the Hydraulic Joint contributed significantly to keeping the jacking forces low”, said AJ Haverly, TBM operator for Bradshaw's microtunnel boring machine, whose careful control of the tunnel boring machine contributed significantly to the smooth drive.

AT A GLANCE	
Project name	Oregon Avenue, sewer rehabilitation
Location	Washington DC, USA
Purpose	Plant management
Time of completion	2018
Specialties	Value engineering proposal, S-curve in rock
Total length	128 m
ID	1219 mm
OD	1524 mm
Alignment	S-curve
Minimum curve radius	190 m
Pipe material	Reinforced concrete
Pipe length	3.05 m
Geology and groundwater	Low permeability, soft rock, little groundwater
Hydraulic Joint	JC 250 / single loop
Guidance system	VMT SLS LT
TBM	Herrenknecht AVN1200
Owner / Client	DC Water
Consultant / Designer	JMT Johnson, Mirmiran & Thompson, USA
Tunnelling company	Bradshaw Construction Corp., USA

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