# ALIGNMENT CONTROL OF DRILLING RODS FOR JET GROUTING BY INTEGRATED MICROCHIPS

Nikolaus Schneider, GuD Consult GmbH, Darwinstr. 13, 10589 Berlin, Germany, +49-30-789090-0, . schneider@gudconsult.de
Mousaab Majar

## ABSTRACT

The technical challenges for accurate drilling positions increase with deep underground structures in inner city areas. Designed for jet grouting, specific sensors have been developed to record the alignment of rods during drilling by integrating microchips into the drilling rods. By feeding the rod with constant electric current, microchips, integrated in special couplings, can be read during the drilling process and tracked on monitors installed in the operator's cockpit. The orientation for the drilling rod is provided by magnetic points and a compass, positioned above ground on the drilling rig. In combination with asymmetric drilling bits, it is now possible to steer the drilling hole to predetermined positions to compensate for deviations in deep bores. This type of drilling rod for jet grouting has been used in Berlin since summer 2019.

**Keywords: drilling rod, microchip, monitor, magnetic point, alignment, couplings, compass, jet grouting**

## TAILOR-MADE SOLUTIONS FOR DIRECTIONAL DRILLING

The art of direction-controlled drilling requires great experience, creative curiosity and engineering commitment. Tunnel boring machines (TBM), drilling rods for oil platforms, gyro-surveyed boreholes for freezing pipes or drilling tools that measure while drilling all have tailor-made solutions for the required application and are fit to the geometrical dimensions.

What solutions can be applied for jet grouting when distinct columns are constructed to form a continuous construction element to seal excavation pits that are exposed to water pressure?

The following presentation introduces how a a standard drilling rod for jet grouting is upgraded into a chain inclinometer using microchips to read the alignment of the drilling rod while drilling. The single components have been designed specifically for the application in the co-centrical drilling rod.

## BERLIN IS THE CAPITAL FOR JET GROUTING

The ground conditions in Berlin were formed by several ice ages which extended south from the Scandinavian islands. The glaciers deposited thick layers of uniform sand, which extend to great depth. Berlin has a very high ground water table that is evenly spread throughout the city, visible by the water level of the river Spree. The geological profile of Berlin in the glacial valley is shown in figure 1, indicating the ground water level and the sand layers. None of these layers is suitable to seal deep excavation pits.

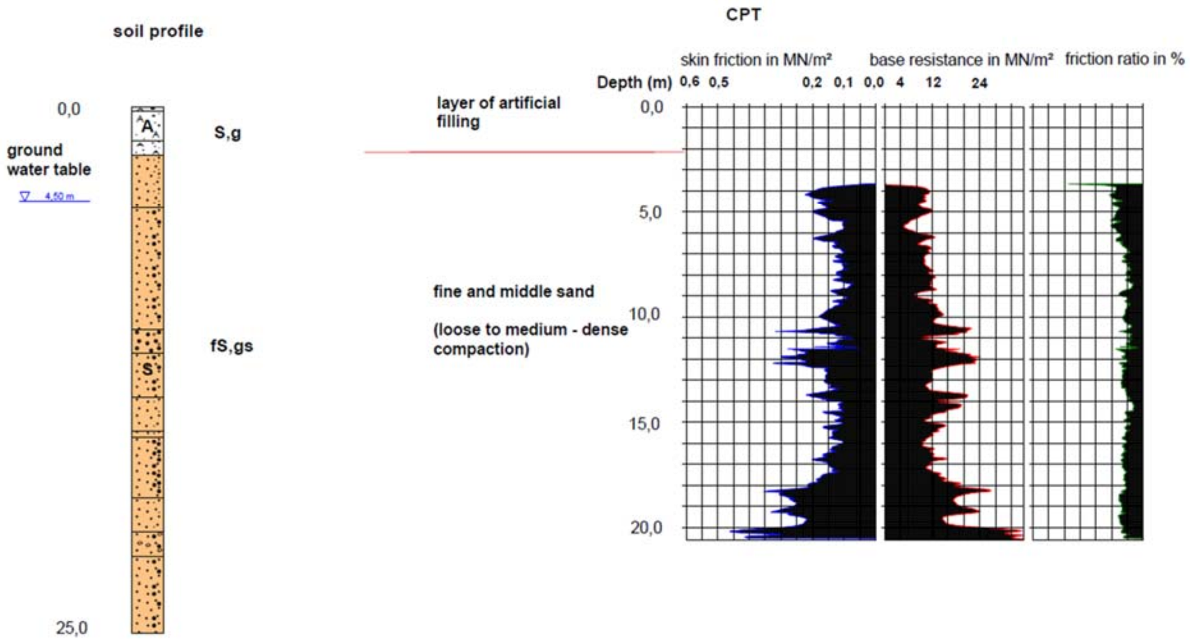



**Fig.1: Typical soil profile in Berlin**

Buildings permits issued by the local authorities articulate stringent conditions in terms of using the ground water for construction purposes. The volume of water to be pumped during construction phase is limited. This results in a construction element for excavation pits that have vertically water tight retaining walls and horizontally artificial sealing layers that turn the excavation pit into a “bath tub”, called “trough tub “.

In addition, the extraction plants for drinking water in Berlin are located in the inner-city area so in terms of environmental aspects, it is quite understandable that the ground water is protected as a precious natural resource like air and soil.
This explains why the majority of excavation pits in Berlin are designed with artificial sealing layer to obtain the building permit.

**THREE DIFFERENT TYPES OF HORIZONTAL SEALS HAVE ESTABLISHED IN BERLIN**

Berlin experienced an enormous building boom after the German reunification. The following construction methods were widely used and adjusted to the relevant constraints of construction sites, designed to protect the ground water quality by reducing the amount of water pumped during the construction phase.

***Injection seals***

These artificial layers constructed for the temporary sealing of the construction pit are built of sodium silicate mixed with a hardening agent which changes the flow characteristics after a defined time. This allows for the sodium silicate to flow into the voids of the sand layer and keep this position thereafter. This horizontal seal for the excavation pit has no structural strength and therefore must be positioned at a depth which balances between the uplift forces of water pressure and the remaining weight of the soil package above the membrane layer. Typical are injection tubes as shown in figure 2, drilled in regular distance with labels for the following injection phase.

**Fig.2: View over the injection tubes**

***Jet grouted seals***

In comparison to the injection layers, the jet grouted sealing slab offers the possibility to use the structural strength of the bottom seal and thus support the retaining walls with a defined abutment. In addition, the position of the jet grouted slab can vary in depth, either downwards with the membrane position comparable to injection slabs or upwards and secured by micro piles. These micro piles are usually drilled after the entire jet grouted slab is cured. The load transfer between micro piles and jet grouted columns relies on bond stress and is monitored by site tests on each project. The length varies between 8 to 14 meters of micro pile length, depending on soil package that has to be mobilized to balance the uplift forces on the sealing horizon. The picture in figure 3 shows the power of the high power beam released from the jetting rod.

**Fig.3: High power beam released from a jet grouting rig**

***Under water concrete slab***

Using the underwater concrete slab method changes the construction site into a small harbor facility where the excavator stands on pontoons and loads the wet sand into dump barges. Figure 4 was taken of the inner-city highway construction site during the excavation phase displaying floating pontons. The sand has to dry in intermediate storage areas before it is moved off site by lorries. The storage facilities must be prepared to collect the dripping water and clean the water prior to pumping it into either the rainwater or mixed water channels. Divers support the excavation work and pump the sediments away prior to concreting the underwater slab. Since there is no overlaying soil package left between the concrete slab and the excavation level, most of the under concrete slabs are tight back by micro piles, drilled from pontons using a special technique to capture and collect the cement based flushing medium from polluting the excavation level.

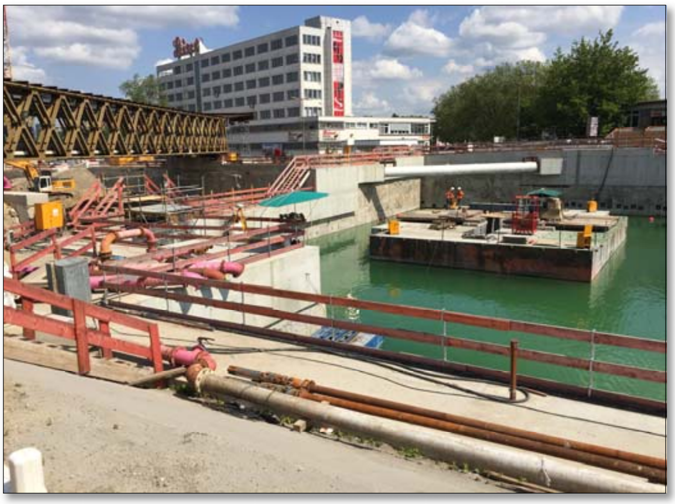


**Fig.4: Working ponton for divers**

***Conclusions drawn after 30 years of experience with excavation pits designed to protect ground water***

The most preferred construction technique is either the injection seal or the jet grouted seal. The choice between these two techniques is dependent upon the detailed soil conditions and the designed depth of the excavation pit. However, the jet grouted seals allow to reduce the excavation depth and to support the retaining wall due to the structural strength of the jet grouted slab. The load transfer to the micro piles within the jet grouted slab is designed on the arch effect. No reinforcement is required for the structural strength.

## ALIGNMENT CONTROL FOR JET GROUTING ROD

The experience gained from many construction sites in Berlin proves that the alignment control of a jet grouting rod is critical to produce watertight construction slabs composed of single columns. To achieve this goal GuD Consult GmbH initiated major improvements in the quality control for jet grouting by upgrading the drilling rod with microchips and thus transforming the drilling rod from „ cold steel “ into a „warm terminal“.

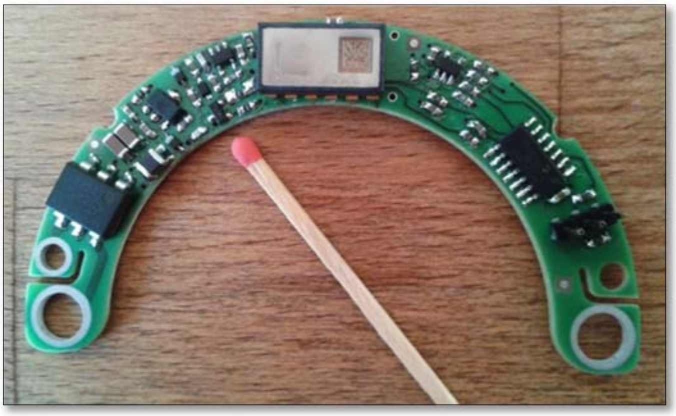


**Fig.5: Microchips designed for jet grouting**

Figure 5 shows specifically designed electronic sensors that are combined and turn the drilling rod into a chain inclinometer, allowing to measure the rod alignment on a built-in monitor in the operators cabin whilst drilling. The task of resolving such a demanding challenge to upgrade a standard drilling rod into a position controlled steering rod required the unique skills of engineers, exploring new ideas and trying to make it work.

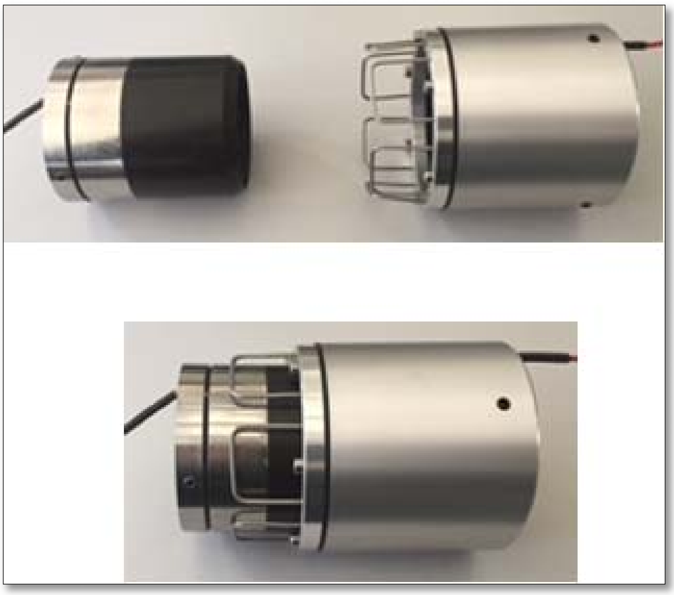


**Fig.6: Special couplings between the rods with integrated microchips**

The microchips as shown in figure 6 are connected using special couplings that allow a transfer of electric current from the base machine into the drilling rod. The chips are built into the couplings and have inclinometer functions in two directions. Each drilling rod is equipped with microchips built into these contact couplings.

**Fig. 7: Inlet of electric current into the drilling rod**

The interface into the drilling rod is displayed in figure 7. It is difficult to geometrically add the inclinations in the different rods since the positions relative to each other might vary, depending on the way the rods are screwed together. The overall orientation of the entire rod is a major challenge to obtain reliable results. Three key features have been added to address this challenge; i.e. magnetic reference on the surface of the drilling rod, a magnet-point reader to capture the different drilling rods in their actually built-in position in the assembled string and a compass for north orientation on the base machine.

**Fig. 8: Magnetic position reader**

**Fig.9: Magnetic point**

Many construction sites in Berlin previously had buildings on it for many centuries. The destruction of WW II left many of those basements in the ground. If orientation systems built into the drilling rod are

used, the systems may be affected by ferromagnetic disorientation induced by metallic objects in the ground. Positioning the compass on the base machine above ground provides a higher reliability since the orientation is not influenced by ferro-magnetic objects in the ground.
The position reader is shown on figure 8 and the magnetic point as reference on figure 9.

The data sets gained for each jet grouted column are made visible on a monitor located in the operator's cabin (see figure 10) and allow the driver to see the position of the drilling rod while drilling. The currently applied code of practice calls for immediate correction of those drilling holes that are running out of alignment, rather than wait for the position based on the as-built drawing.


**Fig. 10: Alignment on the monitor**

The readings obtained for each drilling hole are sent from the data collector on the drilling rod to a server off-site which provides access to further visualization routines. Project engineers are challenged with a completely new set of routines since all relevant information is provided on a data bank, made available for all project members on different authority levels. The most comprehensive pictures are those which show the daily performance of the drilling rigs using different colors for each day of performance. These visualization programs allow to vary the diameters and determine the critical locations for overlapping, as displayed in figure 11.

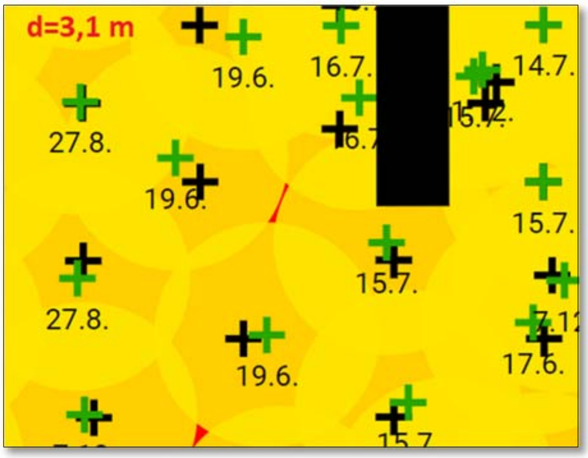



**Fig.11 Critical locations without overlap**

## DETERMINATION OF THE GEOMETRY OF CURED JET GROUTED COLUMNS

The information of the alignment and therefore the position of the jet grouted column is important to find the exact geometry of trial columns at great depths.
Vibration assessment in cured columns enables the project engineers to determine the geometry of trial columns. Therefore, the exact location of both, the cured columns and the agitating column is necessary. The new technique of „down the hole vibration monitoring" enables the determination of the diameter of the hardened columns by jetting against it.


**Fig.12: Test set- up while measuring the diameter of the cured column**

The induced vibrations of the jet beam in cured jet grouted columns allows for conclusions regarding the diameter of the columns, since the speed of rotation of the drilling rod is known. Therefore, the angle of contact can be concluded from vibration. Each rotation of the activating column delivers a contact profile. The real geometry of the trial column can be deduced from contact period.

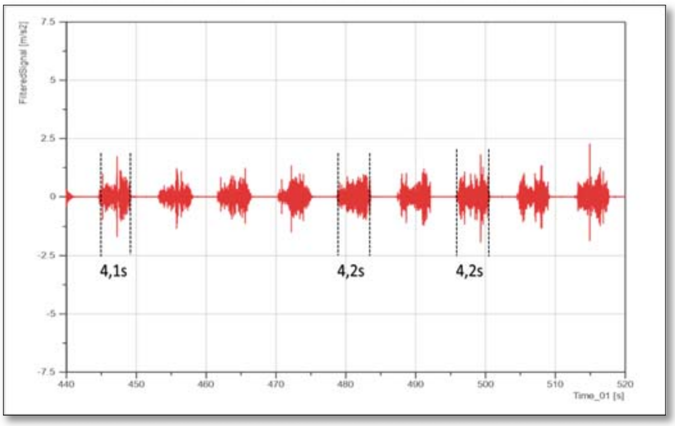
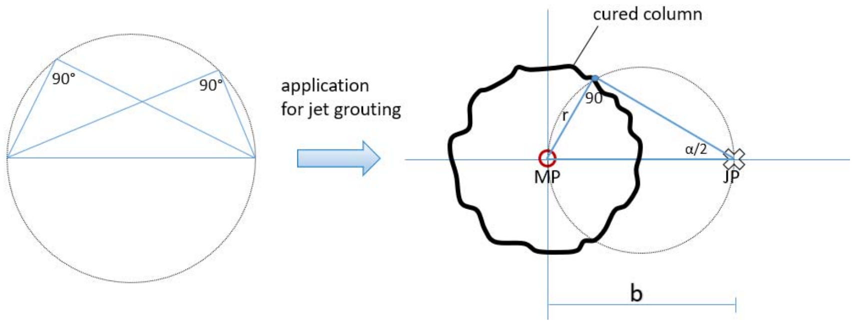



**Fig.13: Contact period of vibrations measured in cured columns**

A vibration reader inside of the primary columns provides signals that can be monitored and transferred into digital signals. By analyzing these signals and applying adequate filter techniques, these readings allow to determine the time while the high-power beam hits the cured column. This information can be transferred into the geometric dimensions of the trial column.




$$r = b \cdot \sin\frac{\alpha}{2}$$

$r$ = radius of cured column,
$\alpha$ = contact angle of jet beam,
$b$ =distance between cured and activating column,
$t_c$ = measured contact period,
w = rotation speed of the jetting rod,
JP = jetting position of the activation column

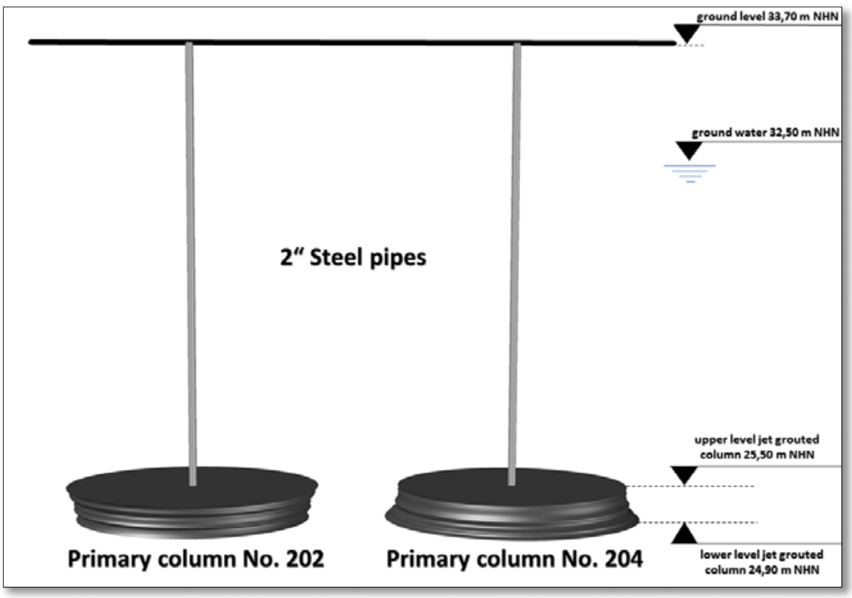



**Fig.14: Scan of the trial column**

The unique information about the location of the magnetic points introduces two further advantages of using this drilling rod. Applying a drilling bit that is asymmetric, enables steering of the drilling rod by using the deviation forces imposed by the bit to the drilling rod. This enables the operator to correct drilling positions that are already deep down in the ground. A secondary advantage is conceivable since the position of the nozzle is permanently known. This is of great advantage for jetting half columns.

**Fig.15: Steerable drilling bit**

## SUMMARY AND CONCLUSIONS

The technical solution to connect two jetting rods using special couplings that are tailor-made for the requirements of high-pressure application is the true masterpiece in this innovation.

In addition, these couplings contain sensors and connect the rods in a way that they provide electric conduction. This concept enables the transfer of electric current and transmission of information from the sensors along the axis of the drilling rod to a monitor that displays the rod alignment. These improvements transform the drilling rod into a chain inclinometer that displays the entire drilling rod over a continuous stretch rather than in polygon sections.

The first construction site in Berlin using microchip rods started in Summer 2019. Meanwhile 12 projects have been completed with horizontal jet grouting slabs in depths between 8 m to 20 m, all of them watertight in accordance with the regulations of the building permits.

The technical advancements of alignment control while drilling, the exact determination of geometry at each depth and the permanent direction and jetting control essentially upgrade the jet grouting technique to a higher quality standard.