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**Only Visualisation?!**

Christof Gipperich

Does visualisation merely supply lovely images or is it really useful for infrastructure projects?

Infrastructure • Project management • BIM • Visualisation • Communication • Efficiency

7  **Geotechnics**

**Demanding Special Foundation Engineering Works for the Jeddah Tower Project in Saudi Arabia**

Harald Heinzelmann

In Saudi Arabia, at Jeddah’s northern coastline, in the urban district of Obhur the Jeddah Tower (formally known as Kingdom Tower) is being constructed as the centre of the planned district Kingdom City. The foundation works for the Jeddah Tower constituted a major challenge due to the great length of the foundation piles and the construction soil. Saudi Bauer Foundation Contractors Ltd., a subsidiary of Bauer Spezialtiefbau mastered the task very well as described in this article.

Geotechnics • Skyscraper • Foundation • Special foundation • HSE • Quality

10  **Geotechnics**

**Innovative, future-oriented Dyke for the North Sea Peninsula in Schleswig-Holstein, Germany**

Daniel Cammarata

The need to upgrade the Alter Krog Dyke, at Nordstrand, on the North Sea peninsula in Schleswig-Holstein, had become critical, following an increase in the number of storm surge incidents, with the potential to cause damage. The project saw the first ‘climate change-resilient profile’ on a dyke in Schleswig-Holstein, with the sea-facing slope being formed at a shallower slope than the land side. Additionally, the crest was widened, giving the potential for the dyke to be raised further, should sea level rise. This report explains how the challenges posed by the low bearing capacity soils beneath the dyke were overcome, with a cellular mattress system, comprising geosynthetics and coarse fill, used to create a stable and economical foundation.

Geotechnics • Dyke construction • Geosynthetics • Reinforced earth • Stability • Efficiency

17  **Geotechnics and Product News**

**DuoLiner HGS – an innovative Protection System for producing Earth Cables and Pipelines in General**

Nico Gose, Ulrike Ahlers and Jan Schröder

Construction machines frequently cause damage to pipelines during earthworks. Protection systems used customarily for trench and pipeline construction revealed potential for development and improvement during a field test. The further development of a protection geocomposite composed of a sand layer between two woven geotextile layers from landfill construction to create an innovative hydraulically bound protection membrane affords high mechanical resistance, a good signal effect and straightforward execution of laying.

Geotechnics • Pipeline construction • Innovation • Geosynthetics • Protection • Geocomposite

21  **Tunnelling**

**Variable Density TBM – combining two soft Ground TBM Technologies**

Karin Bäppler, Frédéric Battistoni and Werner Burger

Tunnel alignments with variable ground conditions have become commonplace challenges for many underground projects. The conditions along the course of the tunnel often range from stable rock faces to soft, water-bearing soils. Standard technologies for shielded TBMs (Tunnel Boring Machines) have been optimized to handle a wider range of specific ground conditions. Technical and commercial limits are often reached when variable ground conditions become too large. Without major mechanical modification, innovative Variable Density TBMs combine the two basic closed mode soft ground TBM technologies, by maintaining permanent control of face pressure. This article explains the stages in developing Variable Density TBMs as well as their manner of functioning and looks at applications in major projects in France, the USA, Malaysia, Peru and Australia.

Tunnelling • Driving • TBM • Soft ground • Variable geology • Development • Major projects

28  **Tunnelling**

**Analytical Approach to determine Gripper Pretensioning Force for Driving Tunnels with a Gripper TBM**

Jürgen Schmitt and Wahid Khadr

Gripper pretensioning force represents an essential parameter for deciding on the application of a Gripper TBM for driving a tunnel in hard rock. This article deals with a new approach for calculating a simplified evaluation of the gripper pretensioning force involving only a few initial parameters.

Tunnelling • Driving • TBM • Gripper • Calculation method • Data analysis
Road Heading in small Cross-sections – conventionally and mechanised with Roadheaders

Andreas Mozar

Road heading in small cross-sections in mining and tunnelling requires suitable excavation methods and machine technology. This article deals with selection criteria for conventional driving as well as partial face excavation with roadheaders and provides an overview of the machine technology available on the market.

Mining • Tunnelling • Driving • Machines • Suppliers

In situ Biobleaching of polymetallic Sulphide Ores – Conditioning Methods for enhanced Permeability in crystalline Rock Formations

Ralf Schlüter and Helmut Mischo

The Bergakademie Freiberg University of Mining and Technology and the Dr. Erich-Krüger-Foundation established the “Freiberg Biohydrometallurgical Centre” (BHMZ) to foster interdisciplinary research along the entire biomining and biohydrometallurgical process chain with a focus on the extraction of indium from polymetallic sulphide ores. The objective of the BHMZ is to establish this value chain through interdisciplinary cooperation of various institutes, covering the fields of geoscience, mining engineering, microbiology as well as analytical and technical chemistry. The Department of Underground Mining Methods deals with the design and implementation of a pilot-scale underground testing facility for microbial in situ leaching in its “Research and Educational Mine“. Different conditioning approaches based on hydraulic and explosive methods for enhanced permeability in the rock formation are considered.

Mining • Research • Process • Leaching • Sulphide ores • Testing • Underground

Main Mine Fan “Made in Germany” for the Uvalnaya Russian Coking Coal Mine

Patrick Schneider and Corinna Both

Efficient and reliable ventilation is essential for the next working field to be opened up at the new coking coal plant Uvalnaya in the Kuzbass region in the south-west of Siberia. Towards this end, the CFT GmbH Compact Filter Technic in conjunction with the Kordmann Lufttechnik GmbH has devised, manufactured and provided a new type of main mine fan after adhering to a strict timetable.

Mining • Russia • Coal mine • Ventilation • Product development • Industrial safety

Innovative explosion-proof Switchgear for the Use in Energy Distribution Applications or as a Motor Starter

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Cover:
During the lifespan of an oil well with EOR methods apply. With the help of various media, the pressure in the deposit could be increased, the viscosity of the crude oil could be enhanced and the flow path could be widened. With the help of the switchgear 8SN7, the medium voltage can be controlled, switched and distributed within the hazardous zone. The explosive-proof switchgear 8SN7 designed by the specialists at BARTEC can be equipped either with a vacuum circuit breaker for the use in energy distribution applications or with a vacuum contactor for the use as a motor starter.
Read more on page 50.

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Only Visualisation?! 
Prof. Dr. Christof Gipperich, Hochschule (University of Applied Sciences) Biberach, Germany

Does visualisation merely supply lovely images or is it really useful for infrastructure projects?

**Infrastructure • Project management • BIM • Visualisation • Communication • Efficiency**

Digitalising the field of construction under the synonym Building Information Modelling (BIM) is mainly reflected nowadays in the form of increasingly perfect and more detailed three-dimensional virtual CAD models. On the other hand, reliably functioning models extended by the “dimensions” time and money – i.e. deadline planning, calculation and first and foremost, controlling – for their part, still represent individual solutions.

Being aware just how much work and above all, information and advantage is to be found in visualisation, I am somewhat surprised by the extent to which 3D models are sometimes appraised so derogatorily. You have also probably heard pronouncements such as “just lovely pictures” or “young people’s cute gimmicks”? At the same time, 3D modelling and visualisation given proper application and not as an end in itself, represents the most powerful element of digitalisation on the construction sector in the foreseeable future – which is certainly not long in the age of digitalisation.

**Changes in accessing the Customer and User**

Visualisation alters the access to structures for the client and user substantially. This applies to private and public building construction as well as to creating infrastructures e.g. in the case of projects involving citizen participation. After all, for the layman it is namely absolutely impossible to even vaguely comprehend the plans and technical drawings for a building, quite apart from being in a position to express notions about a structure. He has to hope and trust in this case that an expert – the architect in civil engineering – takes over this role and grasps his wishes and conceptions or rather predictions and surmises them. The fact that this far too often does not succeed is reflected among other things in the customary large number of alterations undertaken during the execution phase for straightforward redevelopments right up to complex structural projects. Even the different contractual laws are often designed precisely for this adaptation and alteration mechanism.

Would you still approve investing in a building or making an investment yourself nowadays without first exhausting all the technical possibilities in order to understand the investment as thoroughly as you can? Consider the amount of effort you resort to in order to purchase a car, a kitchen or your next smartphone. Wouldn’t you award the building contract to the guy, who enables you to gain a maximum understanding of the product or building by means of visualisation, providing you with an emotional experience as well as safeguarding your decision? And wouldn’t you – no matter how it may be formalised – demand contractually that you ultimately have the product or building including the emotional experience supplied to you at a fixed price? Do you place your trust in a public client of an infrastructure scheme or an opponent of such a measure before you have comprehended, seen and if possible gauged and experienced which effects the measure will actually have? This enables the following conclusions to be drawn:

- The party, which has the virtual 3D model at its disposal controls direct access to the customer or access to the user and thus, as experience shows, achieves the best results. The parties, who do not control the model, for their part, lose influence and run the risk of being pushed to the side or out of the market.
- All those participating on the market, who base their business model on amended orders, must seriously consider the substance of their business model on account of increasing transparency for customers and users. This also applies to clients and opponents of infrastructure schemes should they desire to assert their particular interests with specific intransparency.
- Jurisprudence and legal standards must be adapted. Should – as already mentioned – virtual structural models and virtual experience become the contractually due performance, ultimately the judge will compare the virtual model that is purchased with the building actually set up. Woe betide the bidder, who in future “optimises” his virtual model during the purchasing process in the interest of a sales strategy.

Further aspects will undoubtedly occur to you! At any rate, visualisation via transformed customer access essentially changes the value creation chain in construction as well as the business model.

**Increasing Productivity through improved Team Communication**

In addition, 3D modelling and visualisation improve communication among those involved in construction and in turn, productivity, and consequently competi-
Gipperich: Only Visualisation!!

Only Visualisation?! has been professor for project management in infrastructure construction and in the field of energy as project manager, branch manager and divisional manager with Hochtief for more than two decades.

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References


It is no secret that the productivity of management processes in construction processes is increased and that errors and misunderstandings are reduced, the better the mindset of those involved in the discussion is attuned to the building or part of the building – and this applies throughout the entire value creation chain. What can contribute better in this respect than a three-dimensional virtual image of the building?!

It becomes even more complex if construction methods and construction sequences are to be tackled, in other words if “how is it to be built” must be debated alongside “what is to be built?” Not only is a time-related component then added but additionally information relating to construction equipment, ancillary construction measures and construction stages. Here we are talking about real construction sequence simulation as distinguished from visualisation of deadline plans. Would it not be wondrous progress indeed if the production of a building with all equipment and ancillary construction measures etc were to run like a film before our very eyes prior to returning to reality?

At the Hochschule Biberach I asked a group of students in the 2017 summer semester to work out a plan of execution for modernising a hydro power plant. The basis was provided by a 3D model, which had been produced during the previous semester. I was able to identify breathtakingly simply and quickly the thought processes, which were not surprisingly strewn with errors, and guide them towards the right solutions from the engineering viewpoint, although the students had only worked with simple 3D phase models.

Today I would no longer approach project management assignments without the tool of visualisation. One’s personal experience is backed up by corresponding studies from the Scandinavian and Anglo-Saxon countries [1, 2], which Fuchs [3] reviewed in his bachelor thesis. In my view, there is no doubt that the visualisation of buildings and construction sequences significantly improves communication over and above the value-creation chain, decreasing information breaches thus leading to increases in productivity. I am convinced that enterprises, which miss out on this trend, will find their market position endangered.

Visualisation is thus not at all a gimmick, far rather it will soon considerably change the market in the short term.

Yours,

Christof Gipperich

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It has long been known from brain research just how complex thought processes are to create a three-dimensional image of an object from two-dimensional plans. Expressed simply the thought process functions as follows that we somehow relate the 2D drawings to 3D images or part-images, which we know and have stored and which belong to our personal and very own treasure trove of experience. As a result, two persons, looking at the same plans, also envisage two or less different three-dimensional structures in their head.

It requires a great deal of time and energy to equate the concepts and ideas relating to a building to a reasonable extent – the more complicated the structure the more this applies. Furthermore, far too frequently the communication processes become mingled with hierarchical topics and power issues. And undoubtedly different understandings for solving the issues needing clarification remain in their heads because different structural models impede the thinking process. Incidentally, this consideration provides an answer to the question as to why well-harmonising teams function better. They can look back on the same experiences thus the images in their heads resemble one another more closely.
Demanding Special Foundation Engineering Works for the Jeddah Tower Project in Saudi Arabia

Dipl.-Ing. Harald Heinzelmann, Bauer Spezialtiefbau GmbH, Schrobenhausen, Germany

Introduction

The Jeddah Tower will surpass the Burj Khalifa in Dubai as the World’s highest building; and with a height of 1,007 m it will for the first time ever exceed the magical kilometer limit. The design of the Tower shall represent a desert plant rising to the sky as symbol for Saudi Arabia’s growth and future. Jeddah Economic Company is the client which was founded in 2009 for the development of the Jeddah Tower and the Kingdom City. In October 2012, Saudi Bauer Foundation Contractors Ltd., a subsidiary of Bauer Spezialtiefbau GmbH with its headquarters in the Bavarian town of Schrobenhausen, was commissioned with the execution of the foundation, retaining and earth works and the water management (Fig. 1). These works started on December 11, 2012. Overall completion of the Tower which will be carried out as reinforced concrete structure and have a viewing platform in a height of 610 m is scheduled for 2019.

Saudi Bauer’s Scope of Work

Saudi Bauer’s job comprised the construction of 270 foundation piles with diameters of 1.5 and 1.8 m and drilling depths between 49 and 109 m; 18,000 m3 high-strength concrete and 6,000 tons of reinforcement steel had to be installed (Fig. 2). To check the load bearing capacity, Saudi Bauer had to carry out pile load tests at four piles using Osterberg load cells. Apart from these foundation elements it was necessary to construct a 75 lin. m secant pile wall as retaining element to deepen the core area by 5 m and

In Saudi Arabia, at Jeddah’s northern coastline, in the urban district of Obhur the Jeddah Tower (formally known as Kingdom Tower) is being constructed as the centre of the planned district Kingdom City. The foundation works for the Jeddah Tower constituted a major challenge due to the great length of the foundation piles and the construction soil. Saudi Bauer Foundation Contractors Ltd., a subsidiary of Bauer Spezialtiefbau mastered the task very well as described in this article.

Geotechnics • Skyscraper • Foundation • Special foundation • HSE • Quality

Fig. 1: Jeddah Tower – execution of the foundation, retaining and earth works and water management
Source of the figures: Bauer Group
Challenges

Within the scope of a separate order, preliminarily installed test piles could for the large part not be executed as planned. At this stage at the latest, all persons involved in the project realized that constructing the very deep foundation piles in the existing extremely heterogeneous soil will pose special challenges to the execution staff. Apart from the great depth and the construction soil, Bauer had to especially concentrate on the required polymer stabilization of the piles with lengths of > 45 m, on the adherence of the admissible tolerances and above all on the very high requirements for the pile concrete and the execution of the reinforcement cages.

Demanding Construction Soil

The upper 50 m consist of reef limestone „coral“ which is in most parts heavily porous and fissured, but also has large cavities; it is, however, sufficiently stable without hydraulic support during pile construction. Below, there is up to the final depth, also of the longest piles, mostly sand, in parts solidified, but also starting from a depth of 70 m also interims layers with a thickness of up to several meters of badly graded gravel/sand or conglomerate which is considered very problematic and was decisive for a qualitatively high ranking support. All piles of the types BP-3 to BP-6 (65, 85 and 105 m) reached the construction soil layers below the reef limestone and only the pile types BP-1/BP-2 (45 m) stop above (Fig. 3). As the coast is close by and the coral has high permeability, the ground water is almost at the sea level, approximately 3.8 m below ground level and has almost the same salt content.

Hydraulic Support

All bores were carried out using the Kelly method by adding liquid support with a 5 m long starter casing to guide the drilling tools and as support for the reinforcement cages and the concreting pipe. The short, 45 m long piles situated within the stable corals had to be constructed according to the contractual conditions with „water load“ which was taken from the well installed before. All piles with lengths of 65, 85 and 105 m, however, had to be installed using polymer support instead of bentonite slurry which is usually used in most cases but also react more sensitive in water containing salt.

Tolerances

A few but demanding tolerances were required for the construction of the piles. It was a challenge not to be underestimated for Saudi Bauer to respect them. By taking suitable, project specific steps, especially the required limit values for the position of the pile on capping level, the maximum vertical deviance and the position in height and the centering of the reinforce-
ment cages could be adhered to and in most cases even underrun by far.

**Equipment Deployment**

As Saudi Bauer planned from the beginning high drilling performance, two Bauer BG 28 and two BG 40 drilling rigs were operated on site. Having such a rig pool available allowed Bauer to use each drilling rig with special equipment and the highest possible efficiency. Thus, the site staff installed the guide frame and the starter casing using the first BG 28 and drilled down the coral to a depth of approximately 25 m. Subsequently, the second BG 28 drilled down to a depth of 50 m, followed by the first BG 40 which advanced the borehole to 80 m. The second BG 40 continued with the last 30 m. To achieve the best performance possible, each drilling rig was equipped with Kelly strings and drilling tools optimized for the existing depth and soil (Fig. 4).

**HSE & Quality**

The health and safety of all persons involved in this project as well as the maximum possible protection of the environment had the utmost priority for Saudi Bauer. Stimulating the multicultural staff’s principal awareness of HSE matters was a first step on the project site Jeddah Tower in Jeddah. Numerous information boards put up on site and the daily monitoring compliance by the project management underline in addition the compulsory implementation of the given rules. This was furthermore intensified by regular trainings and instructions of the site staff. In the obligatory HSE-plan, the persistent use of the personal protection equipment consisting of helmet, reflective vest, safety shoes and the clear labelling of danger zones is specified amongst other subjects. In addition, an itemized quality assurance plan was prepared for the Jeddah Tower project and after inspection and approval by the building supervision it was implemented in detail. By consistently following these requirements, the supervising consulting engineers never found a single default and it was not necessary to rework or to rehabilitate the piles during the complete execution period.

**Conclusion**

The foundation works for the Jeddah Tower constituted a major challenge. Saudi Bauer Foundation Contractors Ltd was able to achieve top quality having almost zero accidents and with an outstanding performance due to intensive work preparation and consistently sticking to the „Bauer Group’s Principals“ to the complete satisfaction of the client and the owner, who confirmed this with a „Letter of Appreciation“. With the successful completion, Bauer Spezialtiefbau GmbH and its subsidiary Saudi Bauer once again demonstrated its pioneering role when it comes to dealing with complex and demanding construction works of the special foundation sector.

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The Challenge

The need to upgrade the Alter Krog Dyke, at Nordstrand, on the North Sea peninsula in Schleswig-Holstein, had become critical, following an increase in the number of storm surge incidents, with the potential to cause damage. An approximately 2.5 km section of the Alter Krog Dyke was upgraded (Figs. 1 + 2) between Norderhafen and Strucklahnungshörn. The Schleswig-Holstein regional Coastal Protection, National Parks and Marine Conservation Agency (LKNSH) commissioned the work, which saw this section transformed into a modern and technically-advanced dyke. In the process, the dyke was raised 0.90 m to reach 8.70 m above sea level (ASL).

Furthermore, it was given a new ‘climate change-resilient profile’ – the first time the approach had been used in Schleswig-Holstein – shown in Fig. 3 [1]. The dyke’s outer, sea-facing side was built with a shallower slope than the land-side and the crest widened from 2.50 m...
to 5.00 m. This profile is designed to make it straightforward and economical for the dyke to be upgraded and raised in the future, should sea level increase more than predicted.

The site is underlain by weak soils, including soft clay, up to 12 m deep, creating a significant challenge for the foundation design. Sufficient stability had to be provided both in the long term and to allow safe and economical construction.

This report first gives a brief outline of the originally-proposed design, using vibro stone columns with a cellular foundation mattress system installed to provide a safe working platform. It then gives a detailed description of the design and construction of the foundation system eventually selected, which saw the vibro stone columns omitted and the support provided solely by the cellular mattress.

**The originally-proposed Foundation Design: Vibro Stone Columns**

It was originally planned to improve the weak underlying soils using up to 0.80 m diameter, 4.00 m long vibro stone columns (Fig. 4), at 2.20 m spacing longitudinally and 1.55 m diagonally. It was estimated about 100,000 m of columns would be needed in this 'floating foundation improvement' to provide sufficient support to the dyke as, at 4 m long, they would not extend to the full 12 m depth of the soft layer.

Trial columns were installed to confirm the proposed method. A working platform was first built using Tensar International’s TensarTech Stratum cellular foundation mattress system, to provide support to the heavy vibro stone column equipment [3].

However, unexpected technical difficulties were encountered during the trial column installation. It was found that the lack of lateral support provided by the weak soils at shallow depths, combined with vibration energy used for column installation, meant that aggregate was being lost to the surrounding ground and it was impossible to create stable stone columns. With an additional amount of aggregate of approx. 30% the trial was stopped, and an alternative foundation design had to be developed.

**The chosen Design: A cellular Foundation Mattress System**

**General**

The project team had already been impressed by the bearing properties of the cellular foundation mattress system used to form the working platform, in particular its ability to transfer the high peak loads resulting from the installation of the trial columns into the weak ground beneath, without major deformations. As a result, Tensar International was invited by the contractor to undertake further investigations, with the aim of developing a ‘floating’ raft foundation using its cellular foundation mattress as an alternative to vibro stone columns.

**The Design and Performance of the cellular Foundation Mattress System**

The cellular mattress is a three-dimensional, flexurally stiff but flexible foundation unit comprising geogrids (Fig. 5) with a granular fill. The open, stable and triangular cellular structure comprises a geogrid base and cell walls formed with vertical, stiff, monolithic uniaxially orientated HDPE geogrid at their intersections. The individual 3D cells are then filled with suitable granular material (which can be compacted) to create a stiff raft foundation, providing increased and improved stability.

The cellular mattress creates a stiff platform, mitigating the effects of differential settlement, and increas-
ing bearing capacity of the weak ground, enabling the platform to be used immediately by heavy construction equipment. The system is assembled on site by hand, which means construction can proceed, regardless of ground and weather conditions.

**Foundation Design and Calculation**

The modified standard cross-section of the dyke is presented in Fig. 6. “Recommendations for the design and calculation of earthworks with reinforcements made of geosynthetics – EBGEO” [5] covers various applications of geosynthetics. However, the design approach for cellular mattress has not been considered in these recommendations yet. Currently, the only design method for a cellular mattress in the world is provided in the British standard BS 8006-1:2010 “Code of practice for strengthened/reinforced soils and fills” [6], Chapter 8 “Design of embankments with reinforced soil foundations on poor ground”. The section on “Basal mattress-reinforced embankments” (cellular mattresses are sometimes known as basal mattresses in embankment construction) describes the design method and calculations for these types of foundations.

This design method was used to develop the preliminary concepts. Checks were made in accordance with BS 8006, such as determining the available resistance against lateral ‘squeezing’ of the soft soil layer and defining the cellular mattress strength and dimensions to satisfy limit equilibrium conditions. During this preliminary stage, the required tensile strength of the uniaxial geogrid component was determined, based upon the dyke geometry above the cellular mattress system and the undrained shear parameter of the soft soil. The limit equilibrium of this cell structure was verified with the aid of MOHR’s circle of stress (Fig. 7). The cellular mattress system had to be capable of accepting the horizontal stresses generated with sufficient factor of safety applied, based upon the geogrid tensile strength and the mattress geometry.

After preliminary design of the system, a further design step required verification in accordance with DIN 1054-2012 [7], taking the calculation norm DIN 4084 [8] into account. The limit state for the bearing capacity for the overall stability was obtained in keeping with German standards by adhering to corresponding partial safety factors for the stresses and resistances [9, 10]. The calculations were undertaken with circular and polygonal slip lines (Figs. 8 + 9). Using the system parameters determined in the preliminary design stage, it was possible to assess the cellular mattress...
structure using an analytical calculation programme \cite{11, 12}. It was particularly important to define the bearing system correctly, as well as to investigate the various construction stages and final condition. The ground model (Fig. 10) was very complex and included soil parameters for drained and undrained states \cite{13}. The varying tidal water levels also had to be taken into consideration and contributed to a substantial part of the computational complexity.

The computational proofs produced by Tensar International were checked and verified by an external consultant. With the design complete and verified, the green light was given for the construction of the first cellular mattress system for a dyke foundation in Germany. The system was commissioned by the client for contract sections I to V (Fig. 2) covering an area of up to 30 m wide and approximately 1,850 m long (station 0+000 to 1+850).

**Construction and Monitoring**

The construction sequence was as follows:

- Installation of the approximately 25 m wide cellular mattress raft foundation
- Construction of a 5 m wide asphalt wave protection barrier, followed by construction of the new dyke using sand, covered with an approximately 1.10 m thick clay layer
- Construction of the 2.5 m wide asphalt pathway with 4.0 m wide paved recreation zone along the dyke crest
- Installation of an approximately 80 m long flood protection barrier with glass elements (to give views of the sea from the dyke crest) in Norderhafen (station 0+525). This barrier is founded on a 11.75 m long sheet pile wall.

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**Fig. 6:** Standard cross-section for reinforcing the Alter Krog Dyke in contract sections I to V \cite{4}

**Fig. 7:** Determining the cellular mattress structure with MOHR’s circle of stress \cite{3}

**Fig. 8:** Proof with slip circles \cite{11}

**Fig. 9:** Proof with polygonal slip lines \cite{11}
Fig. 10: Ground model for stability proofs [13]

Fig. 11: Results of hydrostatic line measuring [14]
Monitoring was carried out during construction and will continue throughout operation of the dyke to check and verify the behaviour predicted by modelling. The German saying: “trust is good, but control is better” applies, in particular, to innovative designs. As a result, detailed monitoring was carried out on this project, including hydrostatic profile gauge (HPG), used to examine surface and below-ground movements during construction. This method involves measurement of the variation of hydrostatic pressure between a reference level and predefined points in a measuring pipe installed along the dyke. A significant advantage of this technique is its ability to measure changes in elevation despite extremely uneven deformations.

Fig. 11 shows some of the HPG measurements taken in contract section 0+200, which confirm the effectiveness of the cellular mattress system. The load-deformation behaviour can be readily identified from measurements carried out over different periods.

The first measurement was taken on 3 June 2014 (blue line). The deformation line and the fill profile line (representing the volume of fill placed) run level with one another. The green fill profile line (21 June 2014) indicates the start of construction of the almost 3 m high protective wall, starting from a height of 3 m ASL (station from dyke axis 30 to 38). This load was imposed on the front of the cellular mattress and the homogenous green deformation line over the dyke footprint (station from dyke axis 30 to 50) is therefore surprising. On 6 August 2014, the fill profile line indicates the greatest fill height, more than 7 m high over the front of the cellular mattress. Given an assumed density of 19 kN/m³ for the fill, more than 130 kN/m² (13 t/m²) was transferred onto the foundation mattress. The red deformation line does not reflect the high load. A small vertical deformation is discernible (the difference between blue and red lines), but this is distributed uniformly over the entire width of the cellular mattress.

At the end of September 2014, the final dyke profile was built in this section. The light blue fill profile line (29 September 2014) and the brown fill profile line (26 November 2014) essentially coincide, signifying that during this period no work was carried out on the dyke profile. The deformation lines also largely coincide, so it can be concluded that no vertical deformations of note occurred during this time.

All in all, monitoring indicated the robust load-deformation behaviour of the raft foundation. Settlements cannot be avoided but stress peaks can be redistributed in a manner commensurate with the ground conditions. This leads to a situation whereby the underlaying compressible subsoil experiences a significantly-reduced maximum vertical stress, so that settlement is lower.

The construction times defined in the contract were successfully adhered to with the cellular mattress system (Fig. 12). Furthermore, the solution turned out to be considerably more economical than the original vibro stone column design. An estimated 20 % cost saving was achieved by choosing the cellular mattress system.

**Conclusion**

The innovative approach to the dyke foundation, using a cellular foundation mattress system, met the project requirements and delivered a future-oriented ‘climate change-resilient profile’ structure between stations 0+000 to 1+850. The cellular mattress filled with coarse aggregate provided an extremely stable foundation for the upgraded dyke, thanks to its high flexural stiffness, enabling construction to start immediately after installation. This technically valid and economical solution for the dyke foundation was simpler to install over very soft soils than intrusive ground improvement solutions, such as vibro stone columns.

As no excavation is required, the risk of unforeseen ground conditions being encountered during construction is also mitigated. Additionally, there is no need for

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**Coastal Protection Measure – “Nordstrand Alter Krog” Dyke Reinforcement Coastal Protection Station 0+000 – 1+850**

**Dimensions**
- Dyke crest height: 8.70 m ASL
- Dyke crest width: 5.00 m
- Outer embankment: 1:10
- Wave protection barrier: 5.00 m
- Rip-rap: 1:3

**Construction programme**
Work began in spring 2013 and was completed in 2017.

**Construction sequence**
- Installation of the approximately 25 m wide and 0.65 m thick cellular mattress raft foundation
- Construction of a 5 m wide wave protection barrier, followed by construction of the new dyke with sand, covered with an approximately 1.10 m thick clay layer
- Construction of the 2.50 m wide asphalt dyke crest pathway with integrated, approximately 4.0 m wide, paved recreation zones
- Installation of an approximately 80 m long flood protection barrier with glass elements in Norderhafen (station 0+525). This barrier is founded on a 11.75 m long sheet pile wall.

**Client**
Land of Schleswig-Holstein, Ministerium (Ministry) für Energiewende, Landwirtschaft, Umwelt und ländliche Räume (MELUR), represented by the regional Coastal Protection, National Parks and Marine Conservation Agency (LKN-SH) in Husum

**Contractor**
Reinhold Meister Wasserbau GmbH, 94491 Hengersberg

**Design and construction management**
Regional Protection, National Parks and Marine Conservation Agency Schleswig-Holstein (LKN-SH)
a working platform typically required to provide a safe working area for the heavy equipment used to install intrusive foundations – the cellular mattress system itself is the platform.

References
[4] Landesbetrieb für Küstenschutz, Nationalpark und Meeresschutz Schleswig-Holstein: Regelquerschnitt zur Ausführung

Fig. 12: Installing the cellular foundation mattress system [15]
DuoLiner HGS – an innovative Protection System for producing Earth Cables and Pipelines in General

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Prof. Dr.-Ing. Ulrike Ahlers, Department of Water, Environment, Construction and Safety, University of Magdeburg-Stendal, Germany
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1 Introduction

Protection systems providing a signal effect and designed to improve mechanical resistance against external attacks are known from conventional trench and pipeline construction and correspond with the state of the art. At the same time reports of cases of damage appear daily in the public media, resulting from lines harmed by construction machines within the scope of earthworks. According to information supplied by the pertinent professional association around 80,000 cases of damage result in Germany every year caused by construction machines [1]. This fact takes on even more significance against the background of the planned massive scheme for building and expanding the high-voltage and ultra high-voltage cable infrastructure in Germany as well as elsewhere in Europe.

Contemporary, innovative protection installations above the pipeline routes are needed in the trench cross-section to preclude damage to the pipelines as well as danger to human lives, equipment and the environment. It is already evident that the systems that exist are unable to provide the required protective effect, something revealed in practice-related tests.

2 Level of Technology

Fig. 1 shows the basic setup of a trench cross-section for high and ultra high-voltage routes. In keeping with the arrangement of the individual elements in Fig. 1, a gap of between roughly 0.3 and 0.5 m generally exists between the level of the protection system and the pipe crown. Should the applied protection system lack a sufficient mechanical protective effect and the signal effect of the warning tape is not observed by the machine operator, the ducts or lines can be damaged by a single movement of the shovel during subsequent earthworks depending on the type of machine technology and shovel geometry applied.

Furthermore, the applied protection elements must not alter the groundwater table to a perceptible degree thus influencing subsequent utilisation for forestry or agricultural purposes – e.g. by creating impermeable layers and backwater above the protection membranes. Suitable mineral bedding materials beneath the protection systems possess high thermal conductive properties. Thus they are able to transfer the existing heat in the earth from the power cables and secure a lasting, highly effective transfer rate. The gravitative transport of water in the soil – primarily induced by precipitation – extending to the bedding level must not be hampered by the applied protection systems as regular wetting and rewetting of the pipe bedding favours the thermal conductivity function.

The anticipated requirement for suitable cable protection systems in conjunction with future major pro-
Technical Approach for a Solution

Potential starting points for optimised protection membranes are to be found among other things in landfill construction. Sand filled protection mats are applied among other things to protect a convection barrier used for sealing purposes. These are geocomposites: a filling of dry mineral additives is located between an upper and lower woven geotextile layer.

The “DuoLiner MDDS” sand mat produced and marketed by Gq quadrat has been used successfully for landfill construction purposes for many years on end. The abbreviation MDDS in German stands for “Mineral Landfill Sealing Protection Membrane”. As required these protection membranes (average thickness 20 mm) can be produced with widths of up to 2.20 m and lengths of a maximum of 80 m.

On the basis of the “DuoLiner MDDS” concept the Gq quadrat company further developed the system in conjunction with its partners – including the Magdeburg-Stendal University and upi UmweltProjekt Ingenieurgesellschaft mbH, Stendal – among other things by including suitable additives (e.g. various binding agents) to the sand filling. “DuoLiner HGS” (Fig. 3) is the name accorded the new protection element arrived at through modification. The abbreviation HGS in German stands for “Hydraulically Bound Protection Membrane”.

A compact protection element resistant to stress and pressure has been devised by developing the strength of the mix in the mat interior making use of the intrinsic moisture from the surrounding earth combined with the tensile strength effect of the surrounding woven geotextile.

4 Hydraulically bound Membrane

4.1 Mechanical Resistance

The strength development of the new hydraulically bound protection membrane was depicted using mat samples with the dimensions 300 mm x 300 mm in lab lysimeters (Figs. 4-A and 4-B). The test duration under realistic precipitation simulation on the lysimeter unit amounted to 28 days. Lysimeters are tried-and-tested examination units used in soil science, environmental research and agriculture for establishing groundwater resource parameters (seepage rate, evaporation). In this particular case the mat samples were installed in small-
scale lab lysimeters (internal diameter 60 cm, height of vessel 50 cm) and involved several series of tests. The moisture needed for binding was acquired by the mix in the interior of the mat: first of all from simulation of precipitation and then proportionally through using the moisture from the surrounding filling material, a sand-silt mixture. However, no decisive changes were registered in the water content in the filling material between the start and end of testing, such as waterlogging above the mat samples or dehydration zones beneath the mats.

Once the mat samples were removed from the lysimeters the flexural strength of the samples was examined in accordance with Appendix F of DIN EN 1339 [2] (Fig. 4-C). The initial load amounted to 10 N for each individual test. As the trials progressed, the tests were conducted under a constant increase in load of 2 N/s until the material fractured or the discontinuation of testing.

It has been established that a significant increase in strength can be presented visually and metrologically for the mat samples making use of ground moisture and infiltrating precipitation in the soil. Furthermore it was observed that a residual bearing capacity can be accorded the surrounding woven geotextile once the consolidated mix in the mat interior has reached its ultimate limit state. The cement stone matrix has in part bonded with the woven geotextile thus attaining a tensile strength effect (Fig. 4-D).

Based on the dimensions of the HGS membranes with widths of up to 2.20 m and lengths of up to 80 m, an increased mechanical resistance effect exists given selective local stresses as in the case of typical digging activities with mechanised equipment technology in foundation engineering. Not only the strength development of the mix in the mat interior combined with the tensile strength effect of the surrounding woven geotextile contributes to improving the protective effect. In addition a HGS membrane that has been laid and has hardened develops a perceptible resistance through the entire mat being installed in the surrounding earth, which cannot escape notice during excavation work.

### 4.3 Project-specific Adaptable

In terms of the protective effect that has to be attained and the on-site conditions at the location both the mix for the mix in the mat interior as well as the fabric used can be adapted specifically for the project in hand. In this way, a protective element tailored to the concrete needs can be devised and produced. The following alternatives are essentially available:

- Mix in the mat interior
  - Varying the grain size \( d_{\text{grain}} \leq 4 \text{ mm} \)
  - Varying the proportion of binding agent
  - Varying the type and quality of binding agent
  - If needed the inclusion of further additives or admixtures
- Double spacing woven geotextile
- Use of coated or uncoated woven geotextile
- Varying the geotextile colour
- Additional tensile force reinforcement through using threads and yarns with high or ultra high tensile strength

### 4.2 Visual protective Effect

A conventional warning tape often provides a corresponding signal effect in the case of a manual operation. If there is a lack of information about lines that have been laid on the spot so that workers on-site are unaware of this, the retrieved and contaminated warning tape is not necessarily noticed during digging operations involving corresponding machine technology.

Woven geotextiles in project-specifically determined signal colours can be used for the HGS membrane and also provided with additional warnings. For this purpose corresponding coloured fibres or yarns are already used when producing the textile (Fig. 5). Compared to a narrow warning tape a large-area coloured HGS membrane represents the optically more easily identifiable and sustainable warning.
4.4 Process Engineering

DuoLiner HGS membranes are protected against the elements with a foil cover and delivered on-site in rolls. The membranes are flexible at the point of being laid or rolled out. The process is executed simply and rapidly using conventional equipment technology (Fig. 6). An additional wind safety device which is customarily required during the installation phase for other geotextiles such as geogrids, geomembranes and PE boards, is unnecessary owing to the high intrinsic weight of the membranes. Providing corresponding equipment technology is available for use on-site, it is possible to lay DuoLiner HGS membranes in the trench without workers actually being present in the trench itself. The outlay for laying (required time, personnel and equipment) is thus low. This aspect is of economic interest especially against the background of the size of the planned, kilometre-long line construction sites for setting up high and ultra-high voltage cable routes.

5 Summary

DuoLiner HGS membranes represent a straightforward and effective protection system for cables laid in the earth. It complies with the high safety requirements for high and ultra-high voltage cables laid underground. Thanks to the strength development of the mix in the mat interior combined with the tensile strength effect of the surrounding woven geotextile this innovative membrane acts as a compact safety element against stresses resulting from tension and pressure. Its setup and composition can be variably modified depending on use. Further advantages are the visual warning function of the applied fabric, which can be designed in accordance with the customer’s wishes as well as being easy to lay, thus enabling construction to forge ahead.

6 References


Fig. 6: Laying DuoLiner HGS mats – schematic drawing (A) and photo in construction field (B)  
Source: G quadrat
Variable Density TBM – combining two soft Ground TBM Technologies

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Introduction

The objective of today’s underground tunnel construction projects, in particular for clients and project financiers, is to complete the tunnelling structures safely, in time and within the given cost frame. After all, exceeding costs and the allotted time weakens the confidence of clients and authorities and ultimately the confidence in and acceptance of large scale projects among the public. This is why flexible, future-orientated solutions such as mechanized tunnelling technology are becoming increasingly important to clients and customers to achieve the targeted quality and functionality of the project on time and within budget. As today’s projects are more and more designed and implemented in regions and geological conditions that would have been inconceivable a decade ago, specially adapted machine concepts are required to excavate the infrastructure safely below the surface where needed and regardless of prevailing subsoil conditions. Thus tunnel structures are increasingly planned in heterogeneous geologies with sections that can comprise solid rock conditions, soft and water-bearing soils and/or mixed face conditions composed of rocks and soils. Such conditions demand a specially adapted machine design to excavate and line the tunnel safely and reliably without the need for long conversion times to adapt the equipment to the specific prevailing soil conditions.

This article highlights the new generation of soft ground machines that combine the two basic soft ground technologies in one and the same machine. With the design of the new generation of multi-mode soft ground machine it is possible to switch smoothly between the different modes (earth pressure balance (EPB) and slurry) in the tunnel by maintaining permanent and full control of face pressure and this without the need for any excavation chamber interventions. This new machine generation is called the Variable Density TBM and offers both, maximum safety and flexibility in the choice of tunnel face support and discharge of muck.

Development Steps of the new Generation of multi-mode soft Ground TBMs

The first multi-mode TBM was designed back in the 1980s for a tunnelling project that was built in variable ground conditions comprising stable to soft rock, mixed...
face and water-bearing soils. Since then the technology has been continually refined and updated to the high degree of maturity of today’s available machine design, the Variable Density TBM [1].

In 2000, a multi-mode TBM was successfully applied for the road tunnel project Socatop in Paris (Fig. 1). The project comprised the construction of the A86 West Tunnel that forms the final link of the 80 km A86 ring road around Greater Paris. The tunnel has been built to relieve traffic congestion and improve traffic links between the suburbs of Paris. The multimode TBM that was used for the construction of this tunnel had a diameter of 11.56 m and was at that time the first innovative TBM that could be operated in EPB and slurry mode.

The tunnel was built by three of the biggest construction and road industry companies in France, Vinci, Eiffage Construction and Colas. To justify the significant effort of a machine design that is capable to completely change from EPB to slurry mode in the tunnel there must be special project conditions. The Socatop project in Paris featured such conditions. The tunnel has a length of 10 km of which approx. 60 % of the subsurface conditions are soils suitable for the use of an EPB shield. The remaining 40 % of the alignment comprised an optimum condition for a TBM operation with a slurry supported tunnel face. The TBM and tunnelling concept for the project considered in particular that the respective geological formations occurred in long associated sections. Both, slurry shields and EPB shields are operated with a filled excavation chamber and a controlled support pressure for the tunnel face. The major differences between the two operation modes are the properties of the chamber filling such as viscosity, shear strength, density and the type of chamber and face pressure control. With slurry shields, the face pressure is controlled by a remote pressurized air bubble that is in most cases provided by separating the excavation chamber in two compartments by means of a submerged wall. With an EPB shield the face pressure is controlled by the advance speed and muck extraction volume via the screw conveyor speed.

The design of both cutting wheel and excavation chamber does not require any compromises between the operation modes. The major mechanical differences are muck transportation and muck handling systems in the excavation chamber and in the tunnel. Slurry shields use a closed, pressurized slurry circuit with a slurry treatment plant on the surface; EPB shields use a screw conveyor for controlled muck extraction out of the excavation chamber and an open tunnel transport system with muck cars or conveyors. The generous amount of space available with the large diameter soft ground TBM for the Socatop project allowed the parallel arrangements of both muck removal systems in the invert area of the excavation chamber with some minor functional compromises. If slurry operation was required in prevailing geological conditions with possible blocks, boulders or larger stones, a jaw crusher could be moved in from a parking position and activated in front of the suction grid. This required a manual intervention and additional mechanical effort to change the operation mode. With TBM diameters less than 8 m this becomes even more difficult. Although the Socatop project was to remain a unique solution for some long time, it showed conclusively that a complex combination of different technologies can make sense if the project circumstances are right.

In May 2013, Bouygues Civil Works Florida successfully completed the excavation of the Port of Miami road tunnel in Florida. The project comprises 1.2 km long twin-tube tunnels that directly cross the shipping channel and cruise ship terminal with their ends curving off to tie-in the existing road alignments on Watson and Dodge islands (Figs. 2+3). The tunnels accommodate two traffic lanes, curbs, walkways, ventilation fans and additional safety features.

Tunnelling for the Miami Port Tunnel in the Biscayne Bay was realized in porous and variable subsoil conditions of mainly sand and limestone and chloride groundwater. Due to high ground permeability in the

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**Fig. 2:** Port of Miami road tunnel in Florida, USA – view of the construction site

**Fig. 3:** Port of Miami road tunnel in Florida, USA – layout of the tunnel route
porous formation and environmental concerns related to possible loss of slurry into the Biscayne Bay aquatic preserve, an Earth Pressure Balance Machine (EPBM) with a diameter of 12.87 m from Herrenknecht was selected to excavate and line the twin tube tunnels (Fig. 4). The TBM could be adapted to deal with the variable ground conditions of locally high permeability where it was required to control the water and extract the rock at the tunnel face. The machine could be operated both in EPB mode (Fig. 5, otl) with material discharge through the screw conveyor onto a continuous conveyor muck handling system and in a water controlled process (WCP) mode (Fig. 5, otr) with hydraulic mucking as the machine crossed beneath the channel and entered into the highly permeable rocks.

The WCP mode bypasses the discharge gate and the muck is processed directly from the screw conveyor through a crusher and into a slurry pipeline to get pumped to a separation plant on the surface. The system does not incorporate a crusher in the excavation chamber as done in a standard slurry machine. The cutterhead tool configuration is designed to limit the particles that can enter the excavation chamber to a size suitable for the installed screw conveyor. The WCP mode as designed for the EPBM that excavated the Port of Miami tunnels is a simplified system or preliminary step in the development of the Variable Density TBM where a rotary cruisher-slurrifier box was designed in combination with the screw conveyor outlet. The rotary cruisher-slurrifier box has to be moved into a parking position before the belt conveyor can be put in operation.

**Variable Density TBM – a new Generation of multi-mode soft Ground TBM**

The demand of today’s specific project conditions where frequent changes of soils, rocks and mixed face conditions of soils and rocks at the tunnel face are more and more common and this beneath the groundwater table had led to the development – also for small to medium-sized TBMs – to change between operation modes e.g. from a slurry supported face to an earth pressure supported face and this with full control of the face pressure also during the transition between modes (Fig. 6). This new generation of multi-mode TBMs, the Variable Density TBM, combines the individual advantages of each system in one machine. The development of the Variable Density TBM was focused on the goal...
to change between the closed operation modes (slurry and earth pressure face support) in the tunnel without any need of mechanical modification in the excavation chamber or behind the gantry in the tunnel area. The Variable Density TBM can be operated as classical slurry TBM with an air bubble system to control the face pressure and in a full EPB mode. The change between the modes can be accomplished gradually under permanent and full control of the tunnel face pressure and without any need for chamber interventions. This machine can also be operated using a high density in the excavation chamber that would be too dense for classical slurry operation but that would be too fluid for a classical EPB operation.

If the Variable Density TBM is fully equipped it would require two muck transportation systems in the tunnel. In a classical Mixshield mode (air bubble for active face pressure control) a closed slurry circuit is required and if operated in a full EPB mode (dry system) muck cars or continuous conveyors are required. The Variable Density TBM can also be operated with classic earth pressure support in the excavation chamber and closed conveyance in the tunnel e.g. in contaminated soils. In dependence on the specific project conditions one of the two systems may be selected to be the high performance primary system and the other, the secondary system of reduced performance. For all operation modes of the Variable Density TBM the muck is extracted from the excavation chamber via a screw conveyor. The further processing of the muck depends on the operation mode in place and the choice of logistics for material conveying. This can be changed from hydraulic transportation through pipes to belt-conveyor transport or muck car haulage.

First use of Variable Density TBMs for Klang Valley MRT Line 1 in Kuala Lumpur

The first Variable Density TBM was used for the 9.5 km long underground section of the first line of the Klang Valley MRT Project in Greater Kuala Lumpur, Malaysia (Fig. 7). This metro Line 1 will be operated when commissioned below the surface as twin tubes running parallel and as stacked tunnel tubes due to space restrictions in the city area. The tunnel was built in the Kenny Hill and Kuala Lumpur Limestone formation (Fig. 8). The soil structure of the Kuala Lumpur Limestone is demanding due to its characterization of highly erratic karst features with eroded limestone rock beneath a layer of top soil. For a total of 8.6 km, six Variable Density TBMs with a diameter of 6.62 m were supplied to MMC-Gamuda KVMRT. The remaining section of about 1 km was excavated using EPB Shields. The Variable Density machines were specially adapted to the specific subsurface conditions with a potential risk of suddenly encountering cavities. Using then the liquid supported tunnel face principle with an automatically controlled support pressure through air cushion that enables a precise control of the face pressure it could happen that the normal bentonite suspension could drain off continually into the ground or up to the surface. Thus, the idea was raised to use a thicker and heavier suspension to balance the earth and water pressure at the tunnel face. Using thicker and higher density suspensions requires design adaptations such as a high-density air suspension system.
density slurry material (HDSM) mixing plant on the surface where the high density material is prepared (Fig. 9).

Based on the positive application of the Variable Density TBMs for the challenging underground sections in the Kuala Lumpur Limestone formation of metro Line 1 (Fig. 10), four additional Variable Density TBMs are to delivered to Kuala Lumpur end of 2017 to excavate and line an about 7 km long section of the new metro line 2.

**Variable Density TBM for Metro Lima Line 2/4**

The consortium Consorcio “Constructor M2 Lima” comprising ACS, FCC from Madrid, Salini from Milan and COSAPI from Lima purchased two Herrenknecht TBMs, an EPBM and a Variable Density TBM (Fig. 11), for the construction of 35 km of new urban rail for the Lima Metro Line 2 in Peru. The two TBMs will excavate and line a major east-west axis (Ate-Lima-Callao) of the Lima-Callao Metropolitan Region.

One section of the new urban rail line of 11.6 km in highly variable geological conditions that comprises mainly coarse gravel with sand, silty sands and clay and silt will be excavated by means of a Variable Density TBM. The machine has a shield diameter of 10.21 m. The Variable Density TBM can be operated in EPB and slurry mode and can change between operation modes with a continuous setting of face pressure support according to the prevailing geology and this without any need for chamber interventions.

The TBM is designed with a DN1150 double screw conveyor. The twin screw arrangement has a flat gate between the first and second screw and a muck discharge gate at the end of the first screw for the discharge of muck onto a belt conveyor in pressurized or open EPB mode. In slurry mode the discharge gate of the first screw is closed and the flat gate between the first and second screw is open thus that the muck can be discharged into a slurrifier box (capacity of 36 m³) that is installed at the end of the second screw. The slurrifier box contains a stone crusher (jaw crusher) that reduces larger particles to a size suitable for liquid transport through the attached slurry circuit to the Slurry Treatment Plant on the surface. In slurry and high density mode the muck transfer along the screw conveyor is a combination of a mechanical and hydraulic transportation. In case of required simplified crusher maintenance the screw conveyor flat gate has to be closed and the slurrifier box can be accessed in free air.
Variable Density TBM for Hong Kong’s Shatin to Central Link Contract 1128

The Shatin to Central Link (SCL) in Hong Kong is a strategic rail line that stretches from Tai Wai to Admiralty. It connects several existing rail lines and passes through multiple districts in Hong Kong. When finished it will serve areas in East Kowloon that currently do not have any Mass Transit Railway (MTR) service and will also strengthen the linkage between the New Territories and Hong Kong Island.

The Dragages-Bouygues JV has won the contract to construct 2 x 2 tunnels that will form part of a 6 km long extension of the Shatin to Central Link. Tunneling works comprise two eastern tunnels (up-track and down-track) of each approx. 590 m in length that will run from the south ventilation building and the new Exhibition station on the Shatin to Central Link and two western tunnels (up-track and down-track) of each approx. 510 m that will be excavated between Fenwick Pier emergency egress point and the existing Admiralty station. The up-track tunnels are deeper tunnels; the down-track tunnels are shallow tunnels. All tunnels are to be constructed in complex geological conditions that comprise very variable geology that is mainly composed of completely decomposed granite (CDG) with the presence of boulders, corestones and transition zones in mixed face conditions and sections of Alluvium and Marine deposits. These heterogeneous conditions along the specific sections demand the use of two different types of TBMs, a Mixshield with liquid supported tunnel face and the city’s first Variable Density TBM.

Three sections, the two western tunnels and the up-track tunnel of the eastern section are planned to be excavated using a Mixshield. The first Mixshield drive started operation in March 2016. The new generation of multi-mode soft ground TBMs, the Variable Density TBM with a diameter of 7.41 m, was launched on 19 August 2016 to excavate the down-track shallow tunnel section of the eastern tunnels. This section is characterized by large portions within fill material that is frequently composed of rock fill blocks in the previous temporary seawall zone. The Variable Density TBM can continuously adapt to the face density to deal with the demand of the predicted heterogeneous and shallow ground conditions. The TBM can be operated both in a slurry and high density mode. The latter mode is used to cope with the very variable geology associated with shallow cover of locally less than 1D where possible risks such as blow-outs and settlements might have been an issue in slurry mode. As the TBM can be operated also with HDSM the slurry treatment plant on the surface is accordingly designed to supply the TBM with HDSM.

Two Variable Density TBMs for Forrestfield Airport Link in Perth, Australia

Salini Impregilo S.p.A. and NRW Pty Ltd JV were contracted to construct the twin tube rail tunnels for the Forrestfield Airport Link project in Perth, Australia. The Forrestfield Airport Link is a new rail line including two twin tube tunnels that have a bored tunnel length of about 7.14 km. This new rail line will connect Bayswater Junction with Forrestfield. A major section of the alignment crosses beneath the Perth airport precinct. This includes sensitive areas beneath the airport runways, taxiways and buildings.

The expected subsurface conditions along the bored tunnel alignment are characterized as variable; sand, clays and cemented layers are expected to be most prevalent within the proposed tunnel alignment with varying degree of strength and cementation. The majority of the tunnelling ground is expected to be composed of mixed face conditions beneath the groundwater table.

With focus on the predicted varying geological units and their varying strength the application of two Variable Density TBMs is considered. The TBMs with a diameter of 7.05 m will be operated along the entire tunnel alignment in closed pressurized mode to guarantee ground stability during excavation. The machines will when ready, be launched at Forrestfield dive portal, extending westwards and ending at the Bayswater dive portal.

The Variable Density TBMs for the Forrestfield Airport project are configured to operate in closed EPB and in slurry mode with a filled excavation chamber and a controlled support of the tunnel face pressure. Both in EPB and slurry mode the muck is extracted out of the pressurized excavation chamber via the screw conveyor and further processed with liquid mucking respectively hydraulic material transport via a closed, pressurized slurry circuit according to the slurry mode or HDSM operation with a slurry treatment plant on the surface. To support the hydraulic muck transport, the muck is transferred at the end of the screw conveyor into a slurrifier box to liquefy the excavated material. A roller crusher is installed in the slurrifier box that processes the material to a size suitable for hydraulic mucking via a slurry circuit. The two Variable Density TBMs for Perth started tunnelling in 2017.

Conclusion

In the past, a large number of tunnelling projects were successfully completed in sensitive areas. The machines applied to date show the highest technical and quality standards of mechanized tunnelling technology mastering project challenges and individual tasks in the interest of customers, clients and the environment.

With the initial introduction of multi-mode TBM technology in the 1980s and further development in multi-mode technology with the possibility of changing between various operation modes in the tunnel, e.g. from open to closed EPB and slurry mode and also to change between the two soft ground modes, the foundation was laid for the new generation of multi-mode soft ground TBMs, the Variable Density TBMs.
machines, also small to medium sized TBMs, can change smoothly and with continuous setting of the face pressure between the operation modes from EPB to slurry. A major technological advantage of these machine types is that the set face pressure can be kept up also during the transition of operation mode and the need for working chamber interventions is avoided. The number of applications of this new generation of multi-mode soft ground TBMs shows the advantage of having a safe solution at hand even for potential high-risk areas to support a settlement-controlled operation with less impact to man and environment. Most of today’s tunnelling projects feature complex heterogeneous geology and environment with shallow overburden or the demand for crossing beneath important and sensitive structures. The so-called Variable Density TBM is a new generation of the multi-mode soft ground machine with state-of-the-art technology. Demanding projects can be safely and reliably implemented using this technology.

References

Analytical Approach to determine Gripper Pretensioning Force for Driving Tunnels with a Gripper TBM

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1 Introduction

A Gripper TBM is suitable for application in hard rock with average to high tool life. The planning and production costs are higher for mechanised tunnelling compared with conventional NATM. This difference in cost can only be compensated for becoming economically acceptable through higher rates of advance. The rate of advance depends on various factors. Around the cutter head the rate of extraction correlates with the strength of the rock. The greater the strength of the rock, the higher the forces are that must be produced at the cutter head, with the wear on the hard rock discs correspondingly higher. The lower the strength of the rock, the lower are the forces acting at the cutter head as well as the wear on the hard rock discs and the higher the rate of advance. In order to produce the forces around the cutter head, the gripper pads are pretensioned in the rock and conduct the reaction forces into the rock. The lower the strength of the rock, the danger that the rock strength does not suffice, the reaction forces cannot be conducted into the rock and that the rock fractures. It must be observed however that lower reaction forces also accompany lower rock strength, as the forces, which are required at the face in order to remove the rock are correspondingly less. The strength of the rock plays a decisive role for installing the support agents within the unsecured rock area. In the case of lower rock strength more complex support agents are required than for higher rock strength. Ideally no support agents are needed in the case of rock with high strength, and here too the rate of advance and the economy are correspondingly higher.

The gripper pretensioning force $F_{\mu i}$ (Fig. 1) represents an important parameter for deciding on applying a Gripper TBM. In order to be able to estimate the contact force for pretensioning a Gripper TBM in a straightforward manner, an analytical calculation approach was developed, which is presented in this report.

2 Existing Calculation Approach for Estimating the Gripper Pretensioning Force

In 2006, WITTKE published a calculation approach to estimate the Gripper pretensioning force $F_{\mu i}$ [2]. The tangential force $F_{\phi i}$ is in this case activated as a frictional force via the Gripper pretensioning force $F_{\mu i}$ of a Gripper plate $i$ (Fig. 1). Given uniform pretensioning of all Gripper plates, the following calculation approach is attained [2]:

$$F_{\mu i} = \frac{\eta_i \cdot F_{Ti}}{\mu_H} \tag{1}$$

In this case $\eta_i$ represents a safety factor. The static friction coefficient $\mu_H$ between the Gripper plates and the rock is determined as follows [2]:

$$\mu_H = \tan \delta \tag{2}$$

The wall angle of friction $\delta$ is generally represented as 2/3rds of the angle of friction $\varphi$ of the rock. The tangential force $F_{\phi i}$ of a Gripper plate is obtained as the outcome of the tangential force of a Gripper plate on account of the thrusting force $F_{Th}$ and the tangential force of a Gripper plate based on the drive torque $F_{Pr}$ (Fig. 1).

$$F_{Pr} = \sqrt{F_{\phi i}^2 + F_{Th}^2} \tag{3}$$

The quotient from the necessary thrusting force $F_{Th}$ and the number of Gripper plates $k$ is taken for calculating.

![Fig. 1: Schematic presentation of the thrusting forces and drive torques of a Gripper TBM [1]](image-url)
the tangential force of a Gripper plate resulting from the thrust cylinder force $F_{yi}$:

$$F_{yi} = \frac{F_{yi}}{k}$$  \hspace{1cm} (4)

The necessary thrusting force $F_{Th}$ consists of the sum of the contact forces of all discs $F_{c}$, the resistance force from the floor shoe friction $F_{R}$ and a safety margin $\Delta F$:

$$F_{Th} = F_{c} + F_{R} + \Delta F$$  \hspace{1cm} (5)

The following equation provides the tangential force of a Gripper plate resulting from the drive torque $F_{\phi}$:

$$F_{\phi} = \frac{M_D}{2D}$$  \hspace{1cm} (6)

In the equation $M_D$ represents the necessary drive torque and $D$ the cutter head diameter. The necessary drive torque $M_D$ is determined by the sum of the resistance torque of the discs and the scrapers $M_f$ as well as a safety margin $\Delta M$:

$$M_D = M_f + \Delta M$$  \hspace{1cm} (7)

Consequently nine parameters are required for determining the necessary Gripper pretensioning force $F_{Ni}$ according to [2] resulting in a correspondingly high outlay during the calculation process.

3 Newly developed Calculation Approach for Assessing the Contact Force

The following possible interrelationships were analysed among other things by means of regression analyses based on a large number of published research results as well as data from excavations using a Gripper TBM:

- Comparison of the installed thrusting force with the relevant cutter head diameter
- Influence of the disc contact pressure on the necessary Gripper pretensioning force
- Influence of the cutter head diameter on the necessary Gripper pretensioning force given varying disc contact force

In Fig. 2 the influence of the penetration rate $p$ per cutter head rotation $U$ on the necessary Gripper pretensioning force is visualised. The penetration rate $p$ was in the process determined in keeping with [3], in the case of which the equation [8] relating to the rolling friction coefficient of the discs $\mu_d$ depending on the disc diameter $d$ is lent consideration.

$$\mu_d = \sqrt{\frac{p \ mm}{U \ mm \cdot \ p \ mm}}$$ \hspace{1cm} (8)

The studies as well as Fig. 2 show a linear connection between the penetration rate $p$ and the necessary Gripper pretensioning force $F_{Ni}$. In this respect it can be clearly discerned in Fig. 2 that the penetration rate fails to exert any significant influence on determining the necessary Gripper pretensioning force. Given a difference in the penetration rate of approx. 14 mm/U the necessary Gripper pretensioning force increases by only some 60 kN.

Fig. 3 shows the influence of the cutter head diameter on the necessary Gripper pretensioning force given varying disc contact force. Here the analyses indicate that the magnitude of the disc contact force $F_{ci}$ substantially influences the calculation of the necessary Gripper pretensioning force. The influence of the cutter head diameter is also evident in Fig. 3. Thus in the case of larger cutter head diameters owing to the greater number of discs the disc contact force exerts a greater influence on the magnitude of the necessary Gripper pretensioning force. As in the case of the penetration rate, here too a linear connection between the cutter head diameter and the necessary Gripper pretensioning force is evident.

It can be generally concluded on the basis of the analyses that were undertaken that in order to obtain a preliminary estimate of the necessary Gripper pretensioning force without the precise calculation approach in...
In this connection the number of discs $n_c$ can be determined in keeping with the following approach from [4] via the cutter head diameter $D_{TBM}$.

$$Q_{FF} = \frac{F_{ci}}{1,8488 \cdot n_c^{1.018}} \cdot \eta_P \cdot \beta_K \quad \text{..................................................(10)}$$

In this connection the number of discs $n_c$ can be determined in keeping with the following approach from [4] via the cutter head diameter $D_{TBM}$.

Table 2: Tangential Gripper pretensioning forces $F_{ti}$ according to [2] or via regression function and corresponding correction coefficients

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<th>$D_{TBM}$ [m]</th>
<th>$n_c$</th>
<th>$F_{ci}$ [kN]</th>
<th>$F_{ci}$ according to [2] [kN]</th>
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Table 3: Deviation of the estimated tangential Gripper pretensioning force from the tangential Gripper pretensioning force worked out according to [2]

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The correction coefficient $\beta_c$ serves to correct deviations from the regression analysis for equation (10). This can also be established via a potential function. Towards this end the individual correction coefficients from the regression analysis for $Q_{FF}$ are related to the disc contact force $F_{ci}$ and evaluated (Fig. 5).

The dependence of the correction coefficient $\beta_c$ on the disc contact force $F_{ci}$ can be described in this case through the following potential regression function with a coefficient of determination of $R^2 = 0.982$:

$$\beta_c = 2.1089 \times F_{ci}^{-0.336}$$

As a result of the correction coefficient the deviation of the estimated Gripper pretensioning forces from the values determined by precise calculation according to [2] constantly amounts to less than $\pm 1\%$ (Table 3). The newly developed calculation approach only requires three parameters instead of the nine for the precise calculation approach according to [2] thus making it easier to determine the Gripper pretensioning force for a Gripper TBM.

4 Summary

In order to be able to produce the necessary thrusting forces to act on the cutter head of a Gripper TBM it is essential to exert a contact force on the Gripper pretensioning system. An explicit calculation approach according to [2] exists to assess the necessary Gripper pretensioning force. A further calculation method was devised based on regression analyses for working out the necessary Gripper pretensioning force for a Gripper TBM. In the case of this calculation approach the Gripper pretensioning force can be estimated in a straightforward manner by means of the parameters for the disc contact force $F_{ci}$ the number of discs $n_c$ as well as the rock's angle of friction $\phi$.

5 References


Road Heading in small Cross-sections – conventionally and mechanised with Roadheaders

Andreas Mozar, M. Sc., Clausthal-Zellerfeld, Germany

1 Introduction

Small cross-sections reduce the outlay for driving to a minimum and offer the user operational and financial advantages as opposed to larger cross-sections. The need for supporting, material, ventilation and excavating is diminished.

In the following, cross-sections starting at roughly 3 m x 3 m are defined as small cross-sections. Fields of application for small cross-sections include the construction of transport, water or sewage tunnels, ore mining as well as every other branch of mining for excavating cross-passages or evacuation routes. Depending on the mining technology applied the driving dimensions must be laid out in such a way that a clear cross-section is available for transporting the machine technology and for the required installations in the heading.

The working steps following the mining process – scaling, securing, installing the support, loading and hauling – are made more difficult by the constricted space conditions. Depending on the prevailing operational situation difficulties in small cross-sections can occur in particular during the haulage process. Local safety regulations such as adhering to safe distances must be considered when defining the logistics. When applying discontinuous haulage such as trucks or wheel loaders it may be necessary to provide lay-by niches to facilitate a smooth haulage process [1, 2].

The engineering technology for small cross-sections is similar to that for larger cross-sections, however, it must be modified in certain ways with regard to the dimensions. Drilling rigs in this field of application usually possess only a single boom, whereas two to three booms are quite customary in larger cross-sections. Roadheaders (German abbreviation TSM for Teilschnittmaschine) for small cross-sections due to their construction weigh less and their cutting motors possess lower installed power. As a result the maximum cuttable rock strength is negatively influenced because the restoring forces and torques produced by the cutting head making contact with the face are absorbed by the mass of the machine. Owing to the narrow conditions there is frequently no soundproof and dustproof driver’s cab available on the spot, remote control is normally used instead.

2 Selection Criteria

A significant criterion for deciding on the choice of a road heading method is the prevailing geological ground condition. The uniaxial compressive strength of the rock in particular has a major influence on the choice of driving technology. Common uniaxial compressive strength ranges of various rocks are presented in Fig. 1. Apart from the uniaxial strength further geological and geotechnical as well as engineering and human factors exert an influence on the rate of advance [3, 4, 5].
Further aspects for the choice of a certain driving system are the costs (investment costs and operating costs), the efficiency in terms of m/day given strict deadlines, the presence of certain equipment technology on the spot as well as the availability, the amount of assembly needed and the delivery span required for the machine technology. In the design phase, adherence to the exhaust gas regulations must be observed. The degree of automation for the machine technology (automatic drill hole diagrams, transport cycles and profile control for the TBM) can increase the rate of advance and minimise overbreak thanks to greater profile accuracy. Highly developed technical solutions, however, are usually expensive to purchase and the cost of servicing can increase. Furthermore, the operating crew must be well trained. For this reason less complex and in turn, more robust systems can be advantageous depending on the preferences of the operator.

3 Methods of Driving

The market offers a wide spectrum of systems, which are suitable for excavating small cross-sections. A distinction must be drawn between conventional heading using drill + blast and mechanised driving using roadheaders or full-face cutting machines (German abbreviation VSM for Vollschitnmaschine). VSM will be dealt with in a subsequent article.

3.1 Conventional Road Heading

Conventional road heading is suited for all existing rock strength segments depending on the boring method. Rotary boring is suitable for soft ground, for harder rock percussive boring or rotary percussive boring must be applied. Core bit wear mainly depends on the uniaxial compressive strength of the rock, the abrasiveness of the rock as well as handling and servicing. Fig. 2 shows an example of a drilling machine for conventional road heading [8].

Several working sequences that follow one another are characteristic for conventional road heading (Fig. 3). First of all, the drill holes for blasting are produced by drilling machines. This process is followed by filling the drill holes with explosives (manually or using explosive loading and transport vehicles) and then by blasting. After blasting care must be taken to ensure that there is sufficient ventilation to cope with the fumes. The loosened muck is picked up by loading vehicles (mobile loaders, wheel loaders or tunnel loading machines) and either transferred to a transport vehicle or transported autonomously to the tipping point (LHD operation). The loading process is followed by scaling and supporting the section of road that has been produced by means of corresponding engineering technology (scaling vehicle, support manipulators, anchor bolters). After this working step the cycle starts all over again.

Conventional road heading is marked by a high degree of flexibility. The mobile machine technology employed can be relocated quickly – for instance to produce a section in another heading – and the roadway cross-sections can be adapted flexibly. Depending on the branch of mining or excavation method the drilling machines can also be used for production. Given very high rock strengths only drill + blast can be successfully employed. Generally speaking, faults can be reacted to flexibly so that extremely detailed knowledge of the geological conditions is less essential than in the case of mechanised driving.

The working cycle during drill + blast operates cyclically so that it can only be parallelised to a certain extent. The individual working steps are drilling the blast holes, filling them with explosive followed by blasting, loading the muck, securing by scaling and finally installing the support. A great amount of machinery is required on account of the number of partial cycles. Drill jumbos or blasting vehicles, loading and transport systems (wheel loaders, mobile loaders, side tipping loaders, dumpers, trucks etc.) as well as equipment to install the support (assembly platforms, anchor bolters, spraying manipulators for shotcrete) are needed. Combined units are also available. Sequential operation is predefined in terms of time through the dispersal of fumes – usually when shifts change.

3.2 Mechanised Driving with Roadheaders

Roadheaders are capable of producing any desired profile forms – with an even floor – within the working area. Fig. 4 shows an example of a roadheader for mechanised driving.
driving. Low to average rock strengths can be penetrated by mechanised driving. Roadheaders are particularly suitable for tackling bedded or fissured rock. In small cross-sections this is restricted by the service weight and the installable cutting rate for the equilibrium of forces and moments of the necessary cutting power. Given high rock strengths in excess of 80 MPa increased tool and machine wear must be reckoned with owing to vibrations, which can result in diminished tool life and thus reduce the rate of advance. Assessing the predicted rocks with regard to their behaviour during the excavation process represents a considerable cost risk in the calculation phase. As a consequence, a precise forecast of the cutting rate and tool wear represent essential planning parameters [8, 10, 11].

According to GIRMSCHEID the economic limit for roadheaders amounts to net cutting rates ranging from roughly 15 to 20 m³/h in roadway cross-sections up to a size of 20 m² and approx. 25 to 30 m³/h in tunnel cross-sections over 50 m². The most unfavourable case in terms of energy for driving with a roadheader relates to the lack of mechanically activatable division planes such as fissured, bedding or schistous surfaces. The sensibility of a roadheader towards geological-engineering, geological rock characteristics such as toughness, strength, degree of separation and abrasiveness involves risks, which can lead to substantial losses in performance if they are not given proper consideration [12, 13].

Fig. 5 presents an example for the efficiency of a roadheader for a machine produced by the Ukrainian manufacturer YMZ of Type KSP-22. In this case both the production performance as well as the tool wear are compared with each other. The manufacturer has already sold about 300 machines of this type mainly on the Asian and African markets. Four machines were sold to the Slovenian lignite mine Velenje [14]. It is clearly shown in Fig. 6 that the production performance diminishes as the rock strength increases and the tool wear grows given higher rock strengths. The service life of the tools was cited related to the production performance. The tool wear in the diagram is thus related to the wear per tool position. According to GIRMSCHEID the economic limit for cross-sections up to 20 m² amounts to a net cutting rate of 15 to 20 m³/h, with this value being attained at approx. 80 MPa rock strength. The diagram shows that the wear of the picks progressively increases from this point [13].

The influence of the installed cutting rate on the milling performance is shown exemplarily in Fig. 6 on the basis of the performance diagrams for two different cutting motors for roadheaders from the GMS German Mining Solution GmbH, Bischofshofen, Germany. It can be ascertained that a roughly 10 to 15 m³/h high milling performance accompanies an increased cutting rate. Owing to the size restriction in small cross-sections the cutting motor performance is confined within technical limits. The assumed economic limit according to GIRMSCHEID [13] is attained at roughly 60 MPa.
given a 100 kW cutting rate and at roughly 75 MPa with a cutting rate of 150 kW.

Mechanised winning operates very accurately so that the extent of backfill is considerably reduced. Especially given the application of geodetic profile control systems profile accuracies of about ± 5 cm and better can be achieved. Thanks to advancing automation and profile monitoring the roadway contour is further improved. The continuous method of working – and therefore high machine utilization – as well as running working steps in parallel generally speaking enable a higher rate of advance than in the case of conventional road heading of in part more than 20 m/day in the case of cross-sections of 18 to 20 m² and good geological conditions. Continuous conveyor systems should be employed for haulage purposes, e.g. mobile belt systems so that the cutting time is maximised. Through the roadheader’s electric drive and the mechanised rock extraction process no exhaust or blasting emissions occur. The number of machines is substantially reduced. With the mountings attached to the roadheader it is possible to install the support anchors without using any further vehicles. A roadheader operation acts very gently on the rock – compared to blasting – the surrounding rock is only minimally affected and vibrations are avoided, something which is of paramount importance under built-up areas for instance in tunnelling [12, 8]. Fig. 7 displays a comparison of vibration measurements for working steps in parallel only partially possible

In case of the risk of gas, e.g. CH₄, there is a need for more ventilation. Roadheaders place higher demands on the floor quality thus it is not advisable to operate them should the floor conditions be bad so that they could be jammed. Mechanised driving is only economically viable in soft to medium-hard rocks – thus it is advisable to be properly aware of the geological conditions prevailing in the headings. High dust nuisance is prevalent on-site owing to the extraction process. The cutting head is sprayed with water in order to cut down on dust and the ventilation speed is increased. The process of spraying water also serves cooling. These measures can lead to worse climatic working conditions on the spot. Owing to their high service weight, size and undercarriages as well as their electric drives roadheaders are comparatively immobile when operating. Frequently they have to be partly dismantled in order to be repositioned, requiring a greater degree of planning and acrobatic organisation.

Table 1 sums up the pros and cons of conventional road heading. Table 2 lays out the advantages and disadvantages of mechanised headings.

4 Market Overview of available Engineering Technology

Drilling rigs, roadheaders and special equipment, suitable for small cross-sections, are available from various mining suppliers. Table 3 offers a market overview of suitable engineering technology – without claiming completeness.

It must be observed that different drill units can be installed in the case of jumbos. Depending on the prevailing operational situation drilling rigs adapted to the geological conditions can thus be selected. The maximum drillable rock strength in the table thus only relates to a certain preinstalled drilling rig. In the case of the minimum cross-sectional dimensions 1 m in width and 0.5 m in height were added in the case of the drilling rigs and the roadheaders to determine more or less genuine roadway dimensions. With narrower loading tables for the roadheaders possibly lesser roadway widths can be driven.

In order to optimise the cyclic working sequence in the conventional heading a number of manufacturers offer combined units so that firstly the rate of advance can be increased and secondly the number of individual vehicles that are required can be reduced so that the

<table>
<thead>
<tr>
<th>Table 1: Pros and cons of conventional road heading</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pros</strong></td>
</tr>
<tr>
<td>high flexibility</td>
</tr>
<tr>
<td>applicable given high rock strengths</td>
</tr>
<tr>
<td>also for winning</td>
</tr>
<tr>
<td><strong>Cons</strong></td>
</tr>
<tr>
<td>high machine requirement</td>
</tr>
<tr>
<td>blast fumes</td>
</tr>
<tr>
<td>discontinuous method of working</td>
</tr>
<tr>
<td>sequential operation</td>
</tr>
<tr>
<td>conducting working steps in parallel only</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2: Pros and cons of mechanised road heading</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pros</strong></td>
</tr>
<tr>
<td>very good roadway contour (precise profile)</td>
</tr>
<tr>
<td>low machinery requirement</td>
</tr>
<tr>
<td>automation well advanced</td>
</tr>
<tr>
<td>no fume and blast emissions</td>
</tr>
<tr>
<td>generally high rate of advance</td>
</tr>
<tr>
<td>working steps conducted in parallel</td>
</tr>
<tr>
<td>acts gently on the rock (little need for scaling and good inherent bearing capacity of the rock, as fewer crack formations weaken the surrounding rock than in the case of blasting)</td>
</tr>
<tr>
<td>continuous method of working</td>
</tr>
<tr>
<td>little need for backfilling as the profile is accurate</td>
</tr>
<tr>
<td><strong>Cons</strong></td>
</tr>
<tr>
<td>high need for ventilation given threat of gas</td>
</tr>
<tr>
<td>low rock strengths possible</td>
</tr>
<tr>
<td>high demands on floor quality</td>
</tr>
<tr>
<td>dust nuisance</td>
</tr>
<tr>
<td>immobile during continuous operation (partial dismantling required)</td>
</tr>
</tbody>
</table>

![Fig. 7: Exemplary comparison of measured vibration speeds during an excavation involving drilling and blasting and with roadheader [12]](image-url)
costs are diminished. The Hazemag/GHH company offers two system solutions suitable for small cross-sections. The Hazemag Roadheading Excavator (HRE) can fulfill the tasks – drilling, charging, loading, scaling and installing the support (anchors and shotcrete) on its own (Fig. 8), as a result of which the machine park, changeover times and the number of lay-by bays or niches needed can be reduced. This wide range of tasks is achieved by a multifunctional boom, which can accept various attachments, which are required for the working step in question. The attachment units set on the two integrated sliding tracks can be replaced via a mechanical quick-release device. The boom fitted with a vertically as well as a horizontally functioning parallel kinematic system is mainly intended for drilling the blast holes. Furthermore Hazemag provides the Boring Loader (HBL), which can switch between a mounting for blast holes and anchors as well as a shovel for loading purposes (Fig. 9).

The GMS (German Mining Solution) company or Hausait offers in the form of the Hausait Multitalent (HS-M) a combined unit with rigid, offset or telescopic boom and a quick-release system for attachments (Fig. 10). Various shovels, transverse drum cutters, hydraulic hammers, working platforms and drilling rigs are available as extensions. There is no need for frequent repositioning so that partial cycles are reduced.

A comparable multifunctional system is provided by the Czech mining machine manufacturer Ferrit in the form of the Multifunction Loader PSU7000 (Fig. 11). Different shovels, hydraulic hammers, transverse drum cutters and drill mountings are available as attachments. The part cycles within the driving process, just as in the case of the previous machine, are optimized through a diminished need for manoeuvring.

The Ukrainian producer Yasinovatskyi Machine Building Plant (YMZ) markets the MPL-22 (Fig. 12) a combination of drilling rig and continuous loading system. Loosened rock material can be taken over by the loading table and transferred to a connected transport vehicle by the centrally guided chain scraper conveyor. Continuous loading systems such as TSM, HRE and MPL-22 should be combined with continuous haulage systems in order to maximise the time factor.

The German enterprise GTA-Maschinenparksystem offers roof-guided systems in the form of the EMS Drilling Units 6000 and 7600 (Fig. 13), which can both drill anchor and blast holes as well as support lining operations with the aid of a working platform.

**Table 3: Market overview – driving technology in small cross-sections according to manufacturers’ specifications**

<table>
<thead>
<tr>
<th>Type of machine</th>
<th>Machine manufacturer</th>
<th>Model specification</th>
<th>Minimum width [m]</th>
<th>Minimum height [m]</th>
<th>Maximum rock strength* [MPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drilling and loading unit</td>
<td>YMZ</td>
<td>MPL-22</td>
<td>3,30</td>
<td>2,80</td>
<td>100</td>
</tr>
<tr>
<td>Boring loader</td>
<td>Hazemag</td>
<td>HBL 600</td>
<td>2,20</td>
<td>1,85</td>
<td>300</td>
</tr>
<tr>
<td>Drilling unit</td>
<td>Sandvik</td>
<td>diverse</td>
<td>2,50</td>
<td>2,70</td>
<td>&gt; 100</td>
</tr>
<tr>
<td>Drilling unit</td>
<td>Komatsu (JOY)</td>
<td>Vein Runner II</td>
<td>2,42</td>
<td>2,81</td>
<td>300</td>
</tr>
<tr>
<td>Drilling unit</td>
<td>Atlas Copco</td>
<td>Boomer T1</td>
<td>2,30</td>
<td>3,20</td>
<td>200</td>
</tr>
<tr>
<td>Drilling unit</td>
<td>Hazemag (anciently DHMS)</td>
<td>HDT1</td>
<td>2,24</td>
<td>2,06</td>
<td>&gt; 100</td>
</tr>
<tr>
<td>Drilling unit</td>
<td>Mine Master</td>
<td>Face Master 2.1</td>
<td>2,35</td>
<td>2,60</td>
<td>250</td>
</tr>
<tr>
<td>Drilling unit</td>
<td>BAT</td>
<td>SB3 - 6.0 Ex</td>
<td>3,65</td>
<td>2,90</td>
<td>&gt; 100</td>
</tr>
<tr>
<td>Drilling unit</td>
<td>KGHM ZANAM</td>
<td>SWW-1/1H</td>
<td>3,50</td>
<td>2,70</td>
<td>&gt; 100</td>
</tr>
<tr>
<td>Drilling unit</td>
<td>Nordmeyer SMAG</td>
<td>Sprenglochbohrwagen BW</td>
<td>3,78</td>
<td>2,70</td>
<td>150</td>
</tr>
<tr>
<td>Drilling unit</td>
<td>Ferrit</td>
<td>Singlemaster</td>
<td>3,40</td>
<td>2,80</td>
<td>&gt; 100</td>
</tr>
<tr>
<td>Electric monorail system</td>
<td>GTA</td>
<td>EHB-Bohrwagen 7600</td>
<td>4,60</td>
<td>3,60</td>
<td>200</td>
</tr>
<tr>
<td>Mining machine</td>
<td>Atlas Copco</td>
<td>Mobile Miner 40V</td>
<td>3,10</td>
<td>3,60</td>
<td>&gt; 80</td>
</tr>
<tr>
<td>Multifunctional loader</td>
<td>Hausait/German Mining Solution</td>
<td>HS Multitalent</td>
<td>2,16</td>
<td>1,71</td>
<td>120</td>
</tr>
<tr>
<td>Multifunctional loader</td>
<td>Ferrit</td>
<td>PSU7000</td>
<td>2,00</td>
<td>1,71</td>
<td>&gt; 100</td>
</tr>
<tr>
<td>Roadheader (TSM)</td>
<td>Sandvik</td>
<td>MR 341</td>
<td>4,20</td>
<td>2,50</td>
<td>&lt; 80</td>
</tr>
<tr>
<td>Roadheader (TSM)</td>
<td>DHMS</td>
<td>dr R60dr/dh R60</td>
<td>4,00</td>
<td>2,70</td>
<td>&lt; 100</td>
</tr>
<tr>
<td>Roadheader (TSM)</td>
<td>KAMY CHINA</td>
<td>EBZ 90</td>
<td>3,00</td>
<td>2,40</td>
<td>&lt; 80</td>
</tr>
<tr>
<td>Roadheader (TSM)</td>
<td>YMB</td>
<td>KSP-22</td>
<td>4,00</td>
<td>2,10</td>
<td>&lt; 80</td>
</tr>
<tr>
<td>Roadheader (TSM)</td>
<td>Alpine</td>
<td>R-130 low version</td>
<td>3,50</td>
<td>2,35</td>
<td>&lt; 80</td>
</tr>
<tr>
<td>Roadheader (TSM)</td>
<td>Antraquip</td>
<td>AGM 300</td>
<td>3,00</td>
<td>2,15</td>
<td>&lt; 80</td>
</tr>
<tr>
<td>Roadheader (TSM)</td>
<td>MSB Smittwerke (IBS)</td>
<td>SM 130</td>
<td>2,30</td>
<td>2,50</td>
<td>&lt; 80</td>
</tr>
<tr>
<td>Roadheader (TSM)</td>
<td>GMS</td>
<td>MS 310</td>
<td>2,60</td>
<td>2,20</td>
<td>&lt; 80</td>
</tr>
<tr>
<td>Driving machine</td>
<td>Hazemag/GHH</td>
<td>HRE</td>
<td>3,30</td>
<td>3,30</td>
<td>&gt; 100</td>
</tr>
</tbody>
</table>

*The cited maximum cuttable rock strengths only relate to a preinstalled drilling rig, which, however, can be modified according to the needs of the project.

**Fig. 8: Hazemag/GHH HRE [16]**
The roof-guided mode of construction allows good exploitation of the existing roadway cross-sectional area. Thanks to this system high parallelisation effects can be accomplished in conventional and mechanised driving so that the rate of advance is optimised. Furthermore the demands placed on the floor quality are less thanks to the roof-guided manner of construction. The minimum roadway dimensions that are cited relate to an arched support; reduced dimensions are to be expected given a rectangular cross-section. The dinter loader with a width of 1.30 m and 1.40 m in height was selected as the loading machine.

With regard to mechanised roadway heading Atlas Copco has introduced a new concept for road heading or for excavating deposits with the Mobile Miner 40 V (Fig. 14). The roller bits for extracting the rock are assembled on a vertical rotating wheel. This cutting wheel is connected to the machine by means of a vertically and horizontally moving boom. The loosened material is accepted by a loading table and discharged at the back of the machine via belt conveyor. Thanks to the design practically rectangular cross-sections can be produced. So far maximum cuttable rock strengths have yet to be published, however, higher cuttable rock strengths are to be expected than in the case of roadheaders thanks to the roller bits and the machine’s high service weight (200 t). Depending on rock strength the manufacturer declares a rate of advance of 10 to 15 m/d.

5 Summary
Road heading in small cross-sections affords a wide range of applications in various spheres. Corresponding roadway dimensions can be applied both in mining as well as in structural projects. The advantage of compact cross-sectional dimensions is mainly to be found in the precise adaptation to the project parameters and consequently the avoidance of unnecessary overbreak. Small cross-sections in conformance with the parameters lead to a reduction in costs as a result of lower procurement costs, engineering technology, lower follow-up costs for ventilation and supporting for instance as well as a
reduced outlay for the material used such as explosives and tools. In order to avoid complications during the subsequent operational process, the roadway dimensions must be adjusted to all anticipated operational conditions.

In mining the fields of application are to be found in creating cross-passages and evacuation routes as well as heading of different logistically necessary supply routes. In the case of engineering projects a wide range of applications exists in tunnelling.

Tunnels with such cross-sectional dimensions can be used for transport tunnel construction as well as for water and sewage tunnels. The project-related preferences supply the framework conditions for the type of heading. The existing fundamental geological situation represents an important selection criterion. Given higher rock strengths it is only worthwhile choosing conventional road heading. Should lower rock strengths below 80 MPa prevail, mechanised driving methods offer advantages concerning the rate of advance, profile accuracy and vibration emissions – especially in the case of shallow overburden below built-up areas which often exist in tunnelling. Both types of driving afford their specific pros and cons, which must be weighed against each other in accordance with the operating conditions. A decision in favour of a certain type of driving must be taken in keeping with the prevailing operational situation.

The market offers various conventional machines as solutions as well as combined solutions. All forms of road heading are subject to continuous further development. The main features of development relate to automation, digitalisation and optimising machine technology in general. Depending on the preferences of the operators, however, non-automated system solutions will continue to be used.

6 References


Roadway Heading in small Cross-sections – conventionally and mechanised with Roadheaders

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studied Mining Engineering: Energy and Raw Material Supply (specialisation: general mineral resources) at the TU Clausthal and gained his Master of Science degree in April 2017.

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Introduction

A reliable, substantial and sustainable supply of raw materials is of crucial importance for any industrialized country. This dependency applies to "strategic elements" including rare earth elements (REEs), platinum group metals (PGMs) as well as a variety of other metals like indium and germanium which are needed for high-tech industry and products such as electric and electronic devices, fibre optics and laser technology [1, 2]. Due to the economic growth of the BRIC-countries (Brazil, Russia, India, China), the resource policy of China as well as the volatile world market prices of different metals, the availability of these critical raw materials and in turn, dependency of the high-tech producing countries has become increasingly important [1].

An adequate supply is often affected by the increasing depth of deposits, lower metal concentrations and more complex ore mineralogy. In addition, mining activities are more and more restricted by their environmental and social impact and footprints. Consequently, the global mining industry is facing increasing challenges in terms of these geological, technological and social aspects. Hence, conventional mining and processing methods may become difficult to apply in future as they are limited by high energy consumption and technical constraints.

A promising approach to overcome these limitations and constraints of conventional methods, is by applying (bio-)hydrometallurgical extraction methods such as in situ leaching technology (ISL), particularly for low grade ores [3]. Such methods include transforming insoluble metal compounds into aqueous form through bacterial leaching, after which the metals can be selectively separated by solvent extraction and are further refined by electrolysis or thermal processing. Bacterial leaching can also be accomplished in situ within deposits, and is regarded as a combined mining and processing method (Fig. 1).

Boundary Conditions at the Test Site

To localize and implement the in situ bioleaching testing unit within the underground mine, different boundary conditions were considered. The existence of an ore vein with suitable mineralization and thickness is crucial to address bioleaching extraction of sulphide metal ores with the aim of providing increased reactive mineral surfaces and thus enhance permeability in the...
crystalline host rock formation. The main minerals of the preferable formation are galena (PbS), sphalerite (ZnS), pyrite (FeS₂), arsenopyrite (FeAsS) and chalcopyrite (CuFeS₂), with sphalerite is the main target mineral, as it can contain up to 1,560 ppm indium in certain areas [4].

The thickness of the ore vein alternates from a few centimetres up to 1 m in the selected stope and displays a dipping angle of about 50°. Due to former mining activities by overhead cut-and-fill methods, a whole block of 35 m width and 10 m inclined height was predeveloped at a depth of 150 m (Fig. 2). While the head road has a cross-section of approx. 6 m², the bottom road is slightly narrower at about 5 m².

To predict the spatial distribution of the ore within the block and to gather detailed information regarding the rock mass conditions, geophysical methods such as seismics as well as geoelectrical borehole tomography were applied. These measurements provide the basis for further modelling of the interaction between the ore body and in situ bioleaching process.

The seismic wave velocity within the respective block varies from 4,400 m/s up to 6,900 m/s. As illustrated in Fig. 3, single zones of high (red/orange) and low wave velocity (blue) can be identified by showing significant differences in velocity. The interpretation of this wave velocity grid is based on chemical as well as on geological information and has been influenced by mining activities in the past. Thus, the differences in wave velocity describe different mineralogical zones and also provide information about the homogeneity of the rock mass. Zones of low wave velocity most likely represent gneiss and hence less ore mineralization. A high wave velocity characterizes parts of high mineralization and a highly weathered and disturbed ore body, most probably on outcrops in rising drifts. Thus, zones of sufficient mineralization and preferable homogeneity and integrity are decisive for the exact localization of the leaching field in the ore block, to ensure the application of the proposed conditioning methods. These zones are characterized by wave velocities of 5,000-6,000 m/s (green-yellow).
To ensure an appropriate flow and percolation of the leaching agent through the leaching field, the feeding and neighbouring drainage holes have to be hydraulically interlinked. After applying the leaching agent from the head road by pumps via feeding holes in the formation by pressure (Fig. 4), it is collected and drained by drainage holes to the bottom road. There it is collected in a pipe system. Subsequently, the liquid agent solution is pumped back to the head road, regenerated in terms of oxygen supply and bacterial growth and then reinjected into the formation. The recirculation of the leaching agent in the in-situ leaching process is repeated until it turns to a pregnant solution with sufficient concentrations of zinc and indium. Once the concentrations reach the target level, the pregnant solution is preprocessed by membrane filtration (Fig. 5) on site. This allows the barren solution to be recirculated back to the leaching cycle and to process the concentrated solution in the following steps by solvent extraction methods.

**Test Site Design**

As illustrated in Fig. 2, the test site consists of a leaching field within the mineralized and preferably undisturbed zone in the ore body. It is characterized by a borehole grid of feeding (green) and drainage holes (red) with a lateral extension of maximum 10 m. The drainage holes connect the head road and the bottom road with a length of about 8-10 m, whereas the feeding holes are drilled with a length of 5-6 m to provide a barrier of intact rock to prevent leakage when pressure is applied.

**Conditioning Approaches for Permeability Enhancement**

Within the predicted in situ leaching field two different technological approaches for conditioning are investigated and applied. Conditioning itself can be described as permeability enhancement by inducing cracks and fragmentations either by induced water pressure or blasting, and thus creating flow paths and exposing a reactive mineral surface area.

Fig. 6 shows the parallel arrangement of the drill hole grid with alternating feeding and drainage drill
holes. By gathering drill cores with a calibre of 42 mm diameter, detailed information of the rock mass conditions as well as the mineralization can be gathered for every single hole prior to the leaching process and implemented in the geological model.

Conditioning is done independently for every single drill hole set, each consisting of one feeding hole and the two neighbouring drainage holes. The initiation of the respective conditioning method is either conducted within the feeding hole or simultaneously within the whole drill hole set. The distance of the holes initially predetermined at 0.45 m, but also has been adjusted to 0.3 m and down to 0.23 m as well. Decisive for the suitability of the respective method is the borehole integrity. As an optimum case, the complete hole is located within the mineralized vein and does not reveal any disturbance or fractures, ensuring an increasing pressure development at the borehole wall.

The investigated methods, both hydraulic pressure stimulation and water pressure blasting, are hydraulic stimulation methods. A pressure fluid, in this case water, is injected and pressurized in the feeding hole. Regarding the manner of pressure induction and the hole integrity, the fluid cannot infiltrate the rock formation, so high stresses and strains are induced at the borehole wall. Once the applied pressure and subsequently the stress on the borehole wall exceeds the strength of the rock formation, cracks and fractures will be induced.

In general, the crack orientation greatly depends on the in situ stress field of the rock mass formation, which can be described by one vertical ($\sigma_1$) and two, the major ($\sigma_2$) and the minor ($\sigma_3$), horizontal stress components (Fig. 7). The orientation of cracks correlates with the stress ratio of the vertical and the minor horizontal stress component. So that cracks will be induced in a plane perpendicular to the minor horizontal stress [5].

Apart from the in situ stress field of the rock mass, pre-existent weak zones in form of fissures, cracks or contact zones between ore and host rock can reduce the borehole integrity and therefore influence the orientation of the fractures substantially in the small-scale environment within the testing site. These pre-existent weak zones and faults are identified and characterized by drill core sampling and camera inspection (Fig. 8).

**Hydraulic Crack Stimulation**

Hydraulic stimulation of horizontally orientated cracks is conducted with the help of a core straddle packer, which is assembled with two rubber sealing packers each 0.25 m in length, and an injection spacing of 0.33 m in between. Within the borehole the rubber packers brace themselves against the borehole wall and seal the packer tube with the injection space pressure tightly from the rest of the borehole.

After inflation with water and bracing the rubber seals with the borehole wall, water is injected in the space to reach a certain pressure level. As soon as the induced pressure level within the injection space exceeds the crack induction pressure and in turn, the compressive and tensile strength of the matrix at the borehole wall, a long-lasting crack is induced. As the induced pressure level is increased quite slowly to determine the induction pressure, the process can be described as low dynamic.

The conditioning procedure with the core straddle packer in the feeding hole consists of several stimulation sequences at different borehole horizons (Fig. 9). In order to identify disturbed or carbonate-rich horizons, which can inhibit the bioleaching reactions chemically, core mapping and camera investigations are executed. In this way, these horizons can be identified and subsequently eliminated for sequenced conditioning.

The first sequence of conditioning is performed in the deepest horizon of the feeding hole. Subsequently, the assembly is lifted for the next sequence to the pre-
Water Pressure Blasting

The water pressure blasting (WPB) method represents a rather high dynamic conditioning approach to increase the permeability between the drill holes. It is a combination of explosives and water stemming. Detonating the explosives creates high dynamic stresses which are transmitted by water, as incompressible coupling media, on the borehole wall [6]. Compared to hydraulic crack stimulation, this approach shows the potential to initiate multiple radial and horizontal micro-fractures (Fig. 11) on the borehole wall in one step [7]. Due to the high detonation velocity of the utilized detonation cord (about 7000 m/s), a high dynamic pressure is induced instantly on the wall by water exceeding the tensile strength of the formation at several points. The integrity of the borehole wall appears negligible as the high dynamic stress occurs simultaneously on the entire wall abruptly during the conditioning process.

Preparation of WPB requires several steps as depicted in Fig. 12. After drilling the respective feeding and drainage holes, they are filled with water and the detonation cord induced. The length of the induced detonation cord is orientated to the length of the mineralized zone within the feeding hole and can be determined at approximately 3-4 m, neglecting zones of non-integer upper horizons. Subsequently, the borehole mouth is closed and further preloaded with water pressure. The last step is the simultaneous blasting of the neighbouring feeding and drainage holes and in turn, the conditioning of the ore body in between.

As shown in Fig. 10, a comparative measurement for every single horizon is performed by determining the induced volume and the collected volume in the neighbouring drainage holes. Furthermore, a correction of the volumes regarding external inflow is considered as well.

![Fig. 9: Schematic procedure of sequenced hydraulic crack stimulation](image)

![Fig. 10: Balance sheet of hydraulic stimulation in boreholes 1, 2 and 3](image)
in different directions and not only horizontally. To prevent intensive destruction of the borehole wall surroundings, it is essential to determine an appropriate charge for the detonation cord. Hence, the charge amount varies from 100 g/m to 300 g/m, depending on the distance between the respective holes. Akin to split blasting, detonation of the loaded holes is performed simultaneously. This ensures the collision and overlapping of the tensile stresses of the adjoining stress waves and thus a yielding of the rock formation along a direct line in the form of a narrow shear plane.

By investigating and assessing the results of the experiments based on hydraulic stimulation and water pressure blasting, it was possible to increase the permeability under a certain feeding pressure from initially 10 l/h (without conditioning) to 27 l/h by hydraulic stimulation and almost 80 l/h by water pressure blasting for one single borehole set. Nevertheless, in some cases, WPB did not reveal a reliable enhancement. On the contrary, it was observed that permeability was even lowered. This effect can be caused by clogging effects in the wall surroundings resulting in the closure of pore space.

**Conclusion**

The surface application of bioleaching technologies on an industrial scale in form of tank, heap and dump leaching is a successfully applied and well investigated process under consideration of economic as well as technical and environmental points of view. The adaptation of this bioleaching technology underground for non-sedimentary ore bodies was investigated in some pilot projects in the past. But the acceptance of this technology is limited by several parameters and factors that can hinder the application and exploitation of the in situ method. Conventional blasting methods as performed in these pilot tests, create a volume swell of the ore material and thus require the removal of the valuable material. Furthermore, it is essential to develop and maintain the whole underground infrastructure.

Nevertheless, the investigation of in situ bioleaching, for metals other than uranium, has undergone a renaissance in the recent past in the global mining industry, as application in uranium extraction has proven reliable thus turning into a state of art technology in that mining sector within the last two decades. Based on the knowledge gained from uranium in situ leaching, the experience in heap and dump bioleaching operations in combination with permeability enhancement in the petroleum engineering industry can be a potentially viable approach for underground ore deposits. Moreover, it provides advantages concerning economics, as it can be implemented as a remote technology with a high grade of automation.
However, further basic research has to be conducted on these specific methods in order to adapt them for in situ bioleaching to overcome the lack of knowledge and understanding. The approaches and methods described in this paper are also adapted from technologies used in the petroleum industry and the fields of engineering geology. The generation of cracks and fractures with help of a high-pressure tube assembly is performed to determine the in-situ stresses within geological formations or to stimulate fissures in deposits of a fossil nature. Water pressure blasting in terms of permeability enhancement especially for crystalline formation is a rather innovative approach and thus needs to be investigated in more detail under the aspect of orientated crack induction given in situ stress field conditions.

Within this research project the suitability of the presented conditioning methods is investigated in an underground in situ testing facility under real in situ conditions. Moreover, other sub-projects within the research centre deal with pre-concentration and separation of pregnant and barren solutions in situ as well as the reliability of the utilized bacterial strains. The results of these projects and investigations will be adapted and implemented for further upscaling of the in-situ bioleaching facility.

References

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Main Mine Fan “Made in Germany” for the Uvalnaya Russian Coking Coal Mine

Patrick Schneider, M. Sc. and Corinna Both, M. Sc. – both CFT GmbH Compact Filter Technik. Gladbeck, Germany

In the Kuzbass coal field close to the Russian town of Novokuznezk in the south-west of Siberia there is a new coking coal mine – Uvalnaya. The Russian company JSC “UK Sibirskaja” operates this mine. The first coal was mined from the first developed working panel in August 2017. It is planned to start mining further seams successively in a two-year cycle. The basis for this approach is offered by four coal seams with thicknesses ranging from 2.00 to 3.50 m at a depth of 100 to 400 m. Predictions for the future are highly promising: according to JSC “UK Sibirskaja” coal reserves are so great that it is envisaged extraction will continue for a number of decades. In addition, studies and tests have revealed that the coking coal to be found there possesses a number of outstanding characteristics in comparison to other deposits, such as low internal gas pressure.

Main Mine Fan as essential Planning Component

The planning of an efficient ventilation system was of paramount importance for two reasons: to facilitate the underground work carried out in advance for the “Uvalnaya South-West” district, which will be the next to be developed as well as to secure the workplace safety for the miners employed there in future. The planning operations for the complete deposit at the Uvalnaya Mine including the new district were undertaken by the external project institute Kuzbassgriposchacht Kemerovo in Russia. A substantial planning component is the main mine fan for supplying fresh air (Fig. 1).

Remit and Concept

After establishing the amount of air needed for the ultimate roadway network underground, a list of requirements was compiled for the main mine fan to be installed on the surface. In the process the routing and the volumetric flow of the air required in each case were taken into consideration.

The quantity of air to be transported amounted to a volumetric flow of 285 m³/s at a pressure of 4,890 Pa according to information supplied by the Russian project institute. In addition a reverse operation amounting to at least 60 % of the cited volumetric flow was foreseen for a possible emergency.

The company CFT GmbH Compact Filter Technic was commissioned to undertake the development, manufacture and provision of the main mine fan. The internationally active company based in Gladbeck, Germany possesses long-standing experience in the field of dedusting and ventilation technology as well as in heating and cooling air for mining and tunnelling. CFT supplies the Russian market with axial fans from Korfmann Lufttechnik GmbH via their CFT-MMZ Joint Venture based in Russia. After thorough scrutiny of the list of requirements with the engineers of both companies it was established that a completely new Korfmann

Efficient and reliable ventilation is essential for the next working field to be opened up at the new coking coal plant Uvalnaya in the Kuzbass region in the south-west of Siberia. Towards this end, the CFT GmbH Compact Filter Technic in conjunction with the Korfmann Lufttechnik GmbH has devised, manufactured and provided a new type of main mine fan after adhering to a strict timetable.

Mining • Russia • Coal mine • Ventilation • Product development • Industrial safety

Fig. 1: General Layout
Source: JSC „UK Sibirskaja”, supplemented by CFT
The main mine fan would have to be developed to fulfil the requirements put forward by the customer. The concept comprises a two-stage fan with an impeller diameter of 3.0 m and 1 MW drive capacity per fan stage (Fig. 2). A redundant, identical fan was integrated in the planning of the entire facility thus ensuring the requirements of the Russian authorities could be fulfilled with regard to failure safety. The projected system ultimately consisted of two identical, two-stage main mine fans with a motor capacity totalling 4 x 1 MW at an operating voltage of 6,000 V at 50 Hz. The reverse operation was triggered by changing the motor’s direction of rotation.

**Project Planning**

During the further course of the project technical details were evolved, which in particular increased the efficiency, service life and ease of operation of the system (Table 1).

In order to facilitate the handling of materials, precise advance planning was essential during the entire project development phase regarding the dimensions and weight of all components (Fig. 3). As a result, the main mine fan was provided with a modular design so that it was easy to transport and then assemble on-site. The heaviest single component – a 1 MW motor, of which a total of four were installed – weighs 8.2 t. The system weighs a total of roughly 130 t.

In order to enhance the fan’s efficiency a specially developed, explosion-proof drive motor with compact dimensions and very good aerodynamic flow behaviour was used for the system. The special arrangement of the motor terminal box and connecting points particularly contribute towards attaining these flow characteristics.

The fan housing, the protective ring and the guide vanes all specially designed for the project ensure that both the motor and the impeller can be replaced by means of a special lifting beam without the system having to be dismantled should servicing be required.

Furthermore an electro-mechanically operated, mine-approved fan brake was developed in conjunction with Tüschen & Zimmermann GmbH & Co. KG.

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**Table 1: Technical details of the main mine fan**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>2 dAL30-10000</td>
</tr>
<tr>
<td>Design</td>
<td>axial fan (blowing)</td>
</tr>
<tr>
<td>Performance</td>
<td>4 x 1 MW</td>
</tr>
<tr>
<td>Voltage supply</td>
<td>6,000 V / 50 Hz</td>
</tr>
<tr>
<td>Air quantity</td>
<td>285 m³/s</td>
</tr>
<tr>
<td>Air quantity – reserve operation</td>
<td>&gt;60 %</td>
</tr>
<tr>
<td>Pressure</td>
<td>4,890 Pa</td>
</tr>
<tr>
<td>Impeller diameter</td>
<td>3,000 mm</td>
</tr>
<tr>
<td>Number of blades</td>
<td>14</td>
</tr>
<tr>
<td>Length</td>
<td>ca. 24 m</td>
</tr>
<tr>
<td>Width</td>
<td>9,2 m</td>
</tr>
<tr>
<td>Height</td>
<td>4,6 m</td>
</tr>
<tr>
<td>Total weight</td>
<td>ca. 130 t</td>
</tr>
<tr>
<td>Operating mode</td>
<td>24 h/d</td>
</tr>
</tbody>
</table>

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**Fig. 2:** Overview of the operating and reserve fan station

Source: Korfmann

**Fig. 3:** Modular designed main mine fan during the manufacturing process

Source: CFT
which acts as a holding disc brake for the main mine fan. The functional brake is ventilated and closed by means of a three-phase asynchronous electric motor. The air and brake settings are maintained through the drive spindle’s self-locking effect.

**Saving Costs through innovative Damper**

In order to seal the series of fans not in use a multiflap damper was designed, which can be operated electrically in the form of a shutter via a control unit ([Fig. 4](#)). The advantages of this technology: no gate valve is necessary so that practically 4 m of overall height and in turn, substantial costs could be saved in setting up the mine fan building. The damper is straightforward to operate and possesses optimal transport and assembly properties thanks to its split design. Taking the redundant layout into consideration, the required delivery scope was extended to include additional parts such as special transition sections and metal vibration absorbers, which are needed to connect the two series of fans.

**Production and Testing**

In addition to the technical and commercial system planning, the manufacturing process was a core concern for the engineers involved. The tight schedule called for all suppliers to observe deadlines without exception.

After receiving all the parts from the suppliers the fan stations including all trial runs were built within six weeks ([Figs. 3 + 4](#)). As the prevailing factory workload had been taken into account during the design phase by CFT, it was possible to build the systems within the agreed schedule. For a time diesel-operated generator sets and transformers were set up for the trial runs on account of the enormous power requirement of 1 MW per motor and an operating voltage of 6,000 V in order to determine the actual fan performance characteristics. The trials confirmed that the newly developed system effortlessly complied with the parameters cited in the list of requirements. The fan stations underwent various tests and measurements during the test phase lasting several days. The conclusion drawn was that no further adjustments were needed to achieve the required specifications.

**Delivery and Outlook**

Once the entire system had been dismantled into individual parts for transportation, delivery took place as scheduled in August 2017. After the fan stations had been delivered to the Uvalnaya Mine, CFT service technicians assembled the system within a 10-day period ([Figs. 5 + 6](#)). Subsequently various sub-contractors carried out further assembly jobs at the mine and a complete building for the main mine fan was erected. Final commissioning of the fans is scheduled for May 2018.

During the entire project phase from planning to assembly, CFT GmbH and Korfmann Lufttechnik
Main Mine Fan “Made in Germany” for the Uvalnaya Russian Coking Coal Mine

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References


The specialists at Bartec designed a new explosion-proof switchgear for the use in energy distribution applications or as a motor starter. In the control compartment various automation systems can be installed for the control of the 8SN7 itself but also for the communication and data exchange with a central control centre.

With the help of the 8SN7, the medium voltage can be controlled, switched and distributed within the hazardous zone of an Enhance Oil Recovery (EOR) site for example. For the increase of the supply safety, the voltage supply is often set up as a ring (Fig. 1). The switch gears permit easy and safe operability (Fig. 2).

Fig. 1: Example Ring Main Unit (RMU)

Fig. 2: Easy and safe operability

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Innovative explosion-proof Switchgear for the Use in Energy Distribution Applications or as a Motor Starter

Bartec Sicherheits-Schaltanlagen GmbH, Menden, Germany

The specialists at Bartec (own notation BARTEC) have many years of experience in safety technology. Their new medium voltage switchgear type 8SN7 is designed and built for the use in electrical grids up to 11 kV. It is certified according the latest ATEX and IECEx standards for the use in gassy atmosphere and fulfills the requirements of the Ex protection type “Ex II 2G Ex d/e IIB T5 Gb”. The 8SN7 can be equipped either with a vacuum circuit breaker for the use in energy distribution applications or with a vacuum contactor for the use as a motor starter. In the control compartment various automation systems can be installed for the control of the 8SN7 itself but also for the communication and data exchange with a central control centre.

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GmbH completely fulfilled their client’s expectations. Furthermore, at the same time they were able to gain invaluable experience for this new generation of large fans. Participation in the tendering process for the supply of large main mine fans is also assured in future.
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