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CONSTRUCTION MATERIALS AND BACKFILL IN UNDERGROUND MINING
October 5 - 6, 2017

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- Utilization of modern materials and material mixes
- Sealing materials / materials of low permeability
- Materials used for remediation and abandoned mines
- Transport and installation technologies of backfill material
- Backfill management / sustainable deposit utilisation
- Requirements on backfill materials and backfill bodies

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The eleventh GeoTherm will be taking place in its meanwhile successfully established form at 15th and 16th February 2017. Within ten years the combination of trade fair and congress has become Europe’s leading event for geothermal energy.

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Geotechnics • Soil mechanics • Testing • Education • Research • Croatia

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The soil mechanics laboratory of the Faculty of Civil Engineering at Rijeka University in Croatia was recently completed and inaugurated. Dr. Vedran Jagodnik gives a description of the laboratory equipment.

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15 Innovative contactless Anchor Measurement with elastomagnetic Sensors
Patrick Wörle and Damir Dedic

The Dywidag-Systems International GmbH has played a key role in recent years in the development of an innovative measuring principle for geotechnical ground anchors. The measuring principle is based on the elastomagnetic properties of ferromagnetic materials, so-called Dyna Force. The sensors can be mounted on the steel tendon over the anchor free length and the bond length. The measurement of force occurs in the steel tendon in a contactless manner. This report first looks at the physical background of the measuring principle. Subsequently, practical findings, possible fields of application and knowledge derived from them are presented with reference to examples such as the construction pit at the Opernplatz in Frankfurt and the Gran carevo dam in Bosnia and Herzegovina.

Geotechnics • Anchor technology • Monitoring • Construction pit • Dam

Tunnelling

23 Innovative mechanised Installation of the Geosynthetic Sealing System in the Silberberg Tunnel in Thuringia/Germany
Sven Krahberg und Detlev de Vries

The 7,391 m long Silberberg Tunnel on the new Ebensfeld-Erfurt rail route in Thuringia/Germany was driven by trenchless means and lined using geomembranes. Umbrella seals, single-layer and double-layer all-round seals were applied. This article deals with the mechanised installation of geomembrane lining materials using an innovative laying device.

Tunnelling • Sealing • Geosynthetics • Products • Major project • Innovation • Efficiency

Tunnelling

28 Innovative Accessories for Tunnel Equipment and Geosynthetic Sealing Systems for trenchless Tunnels
Ludwig and Felix Meese

Encouraged by queries from the construction industry, the Meese GmbH has developed innovative accessories for sealing geomembranes in trenchless tunnels. These accessories prevent plastic sealing geomembranes from being penetrated and facilitate the attachment of loads and installation.

Tunnelling • Sealing • Geosynthetics • Fixing technology • Innovation • Efficiency
Crossrail Major Project in London – Concrete Logistics with Innovative Concreting Shuttle

Paul Zeder

42 km of tunnels are being built for London's Crossrail project of the century. An innovative concreting shuttle devised by the Karl-H. Mühlhäuser GmbH & Co. KG aids in tackling the sophisticated concrete logistics for the track installation in this major project. Here the focus is on the concreting shuttle and its manner of functioning in continuous operation. Findings obtained during its application are also explained.

Tunnelling • Construction machinery • Concrete technology • Construction management • Major project • Innovation • Supplier

Powerful underground Cooling with the “Pressure Exchange System”

Jens H. Utsch

The “Pressure Exchange System” (P.E.S.) is a technical component, which is applied in a central location for underground cooling facilities. The system forms the interface between the two circuits of a cooling system – the primary circuit, connecting the surface system components of the cooling facility with the underground P.E.S., and the underground secondary circuit, which links the P.E.S. with the consumers (coolers). The P.E.S. effectively fulfils the transfer of temperature between the circuits, an important function so essential for the efficiency of a cooling system. The manner of functioning and the associated advantages of the system are presented in this report.

Tunnelling • Mining • Air cooling • Equipment • Efficiency

Research Project “Mining-RoX” – From 3D Mine Scans to a Mine Rescue Simulator

Thomas Schmieder

A virtual simulator has been developed as training tool to assist people that risk their lives underground for the safety of others.

Mining • Software • Development • Simulation • Rescue • Safety • Training
A short review looking back on approximately 35 years of geothermal usage in Germany and an outlook to the future is given. The importance of international exchange is emphasised as well.

**Geotechnics • Energy • Renewables • Geothermal systems • Research • Education**

Dear colleague and friend of geothermics,

Germany is looking back on approximately 35 years of geothermal energy usage. We want to give a short review and status report as well as an outlook to the future opportunities. Furthermore, we do not want to leave aside the international point of view and exchange.

**German Review**

Most of the applications have been related to shallow geothermal systems for space heating and cooling based on heat pump technologies. Since 10 years deep geothermal systems from 1,000 to 5,000 m depth for power generation and for district heating become more and more popular, leading to holistic energy systems transition processes like the conversion of the district heating network of the City of Munich towards geothermal. In addition more specific applications like the energetic use of minewater from coal mines in the Ruhr-Area, greenhouse heating or thermal storage in 500 to 1,000 m deep reservoirs are also becoming more and more popular for systems integration.

During the past 35 years – starting with the first geothermal plant in Waren (Müritz) to the actual combined heat and power generation plants in Bavaria – over 30 deep systems have been built up and operated successfully in different regions of the country. Altogether they have an installed capacity of nearly 300 MWth and nearly 40 MWel. This increase mainly depends on the favourable regulations of the German electricity market (Renewable Energy Act), which guaranteed electricity generating utilities a feed-in tariff higher than the market price for electricity. However, in recent years it can be observed that the focus of project developers tends to switch more from power towards large scale heat generation and distribution to decarbonize the heating market.

Ground source heat pumps returned to visibility on the German market in the mid 1990s after a first introduction around 1980. A first boom in 2006 was directly related to the oil price rising for the first time above 100 USD/barrel. Today, another 10 years later, about 330,000 systems are producing heat and cooling energy for different types of buildings – from small residential houses with a few kW heat demand up to larger urban infrastructures with a MW-scale demand. The shallow geothermal applications provide about 3,900 MWth installed capacity in total. The increase of ca. 20,000 geothermal heat pumps per year still fluctuates depending on the average price of natural gas and on the funding schemes of the German government. The majority of heat pumps were installed in new buildings rather than in existing infrastructures.

**German Outlook**

56 % of the overall primary energy demand in Germany is related to heat. To reach national and global climate protection targets this heat demand shall be substituted completely by renewable sources up to 2050. Since it is most obvious to feed heat demand by natural heat, the utilisation of geothermal applications have to be expanded intensively – from shallow to deep systems. To reach these goals, a series of large steps must be taken in the coming years: Primarily the potential of all deep
Utilisation of Geothermal in Energy – German Experience in an international Context

Rolf Bracke & Inga Moeck

GZB International Geothermal Centre Bochum

The International Geothermal Centre (GZB) is a joint research establishment of science and economy with a close link to administration and politics. With its broad anchorage the GZB provides a competence and information centre to the public in regard to all queries concerning the utilisation and extraction of geothermal energy. The objectives of the GZB are:

- To transfer technology, know-how and information between universities, economy and the public
- To conduct and foster application-oriented research between various universities and the economy
- To provide education and advanced training to engineers, geoscientists, miners, architects and craftsmen in terms of heat mining and its integration into the structures of buildings and infrastructural systems
- To retrain employees of the mining industry for future energy technologies (“from coal mining – to heat mining”)
- To establish a scientific network of associated universities and research bodies on a national and international scale
- To increase the recognition of geothermal energy and to institute an information service for contractors, planners and interested parties

Contact:
Phone: +49 234 32 10 233
www.geothermie-zentrum.de/en

IGA

The International Geothermal Association (IGA), founded in 1988, is a scientific, educational and cultural organization established to operate worldwide. It has nearly 5,000 members in over 65 countries. The IGA is a non-political, non-profit, non-governmental organization with consultative status to the UN and special observer status to the Green Climate Fund. The objectives of the IGA are to encourage research, the development and utilization of geothermal resources worldwide through the publication of scientific and technical information among the geothermal specialists, the business community, governmental representatives, UN organisations, civil society and the general public.

More information:
iga@hs-bochum.de
www.geothermal-energy.org

GeoResources Journal 1 | 2017
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A WORD ON...
The eleventh GeoTherm will be taking place in its meanwhile successfully established form at 15th and 16th February 2017. Within ten years the combination of trade fair and congress has become Europe’s leading event for geothermal energy.

Geotechnics • Geothermal energy • International • Conference • Exhibition

On 15th and 16th February, Europe’s leading geothermal marketplace, the GeoTherm welcomes the international geothermal industry. The largest event throughout the European geothermal industry is annually hosting over 3,500 visitors and 180 exhibiting companies, all in all from 44 countries. With the international trade fair and the two parallel congresses GeoTherm addresses shallow and deep geothermal energy perspectives and challenges. The eleventh GeoTherm provides a stage for international high-level experts and operators to discuss the latest scientific and industrial developments as well as current geothermal energy policies.

In cooperation with the International Geothermal Association (IGA) and the International Energy Agency – Geothermal Technology Collaboration Programme (IEA Geothermal TCP) a Latin America Symposium will take place at the Exhibition Center
Offenburg on 14th of February 2017. At the Symposium insights into the Latin American geothermal market, resources, research activities, risk mitigation mechanisms and technology transfer opportunities will be provided.

Visitor Information and Tickets
All presentations of the congress are simultaneously translated into English, French and German. The tickets include trade fair, congress participation, the catalogue, simultaneous translation and the subscription to the online library.

Contact: www.geotherm-germany.com

Impressions of the 10th GeoTherm in 2016
Source: Messe Offenburg
Geotechnics – Interview

Visiting the recently completed and inaugurated Soil Mechanics Laboratory at Rijeka University in Croatia

Pier Luigi Raviolo, Controls Group, Milan, Italy

The laboratories on testing materials at Rijeka University devoted substantially to education and doctorates in technical science were recently completed and inaugurated. The equipment assesses the physical and mechanical properties of building materials (concrete, asphalt, stone materials, soils and rocks).

Pier Luigi Raviolo visited the new laboratories with a particular interest in the laboratory of soil mechanics by the head Ph. D. Vedran Jagodnik who granted him a brief interview.

Pier Luigi Raviolo: First of all Dr. Jagodnik, congratulations for the organization and the technological level of testing equipment that you have provided. How did you get the passion for experimentation in the field of soil mechanics and how did you improve your scientific background?

Vedran Jagodnik: Thank you for the congratulations. I think I discovered the true passion for soil testing during my visiting semester, as a part of postgraduate studies, at University of California Los Angeles. I had an opportunity to learn and work under supervision of Professor Mladen Vucetic and his PhD student, now a PhD, Ahmadreza Mortezaie. Earlier during my studies, I had some similar opportunities, but during that visit to UCLA (University of California, Los Angeles) I have discovered what the experimental work in soil mechanics laboratory is really all about. Reading about the tests in the books or scientific papers is interesting but not as much as when you do the test on your own. By observing how the laboratory tests are performed, you can see how the soil behaves and improve your judgement on soil behaviour.

Pier Luigi Raviolo: We have seen that you have already to your credit many scientific publications, both in experimental and in the numerical modelling and constitutive laws of soils. Hence therefore the choice to expand the experimental activity of the Faculty of Engineering?

Vedran Jagodnik: At this time my publications are somewhat limited but I am hoping that due to our geotechnical laboratory expansion the production of research and publication will start. Thanks to Ministry of Science, Education and Sports of the Republic of Croatia under the project Research Infrastructure for Campus-based Laboratories at the University of Rijeka, which has been co-funded from the European Fund for Regional Development (ERDF). I hope that the use of our laboratory will not be limited to basic soil mechanics parameters but also some more complex soil behaviour, both static and dynamic will be investigated. Since we are a small Department, we need to learn quite a lot.

Pier Luigi Raviolo: Your equipment allows both investigations in static range and investigations in dynamic range and for very small deformation levels. I imagine that your choice of equipment is linked to local and regional situations.

Vedran Jagodnik: This is correct. An active fault is very close to Rijeka and small earthquakes once in a while are not uncommon. Dynamic properties of the surrounding soils are still somewhat unknown, but with this equipment we can do a large amount of tests, as mentioned. Although lots of research has been done

Rijeka – not only high Technology Education
Rijeka is the principal seaport and the third-largest city in Croatia. It is located on Kvarner Bay, an inlet of the Adriatic Sea. Rijeka was selected as the European Capital of Culture for 2020. Gradina Castle with the Shrine of the Mother of God located in Trsat – the old Illirian and Roman Tarsatica – is an important attraction.

For more information: http://www.visitrijeka.eu
About Rijeka University in Croatia

The University of Rijeka was founded in 1973 as part of the natural process of expansion of colleges in western Croatia. These date back to the seventeenth century when it was founded the Jesuit Gymnasium, that could boast a level equal to that of the academies of the largest city of the Austrian Empire.

The University currently houses ten faculties and three schools for teachers for institutions of higher vocational education. The University of Rijeka aims to be counted among the top 500 European universities.

The Faculty of Engineering University of Rijeka with its 10 Departments, 34 Chairs, 46 Laboratories, a Computer Centre and Library, is today a modern Higher-Education and Scientific Institution, competitive on the European and world knowledge market.

The Faculty of Civil Engineering began as the College of Civil Engineering in 1969. In 1971 it started its program in Civil Engineering as a part of the Faculty of Engineering in Rijeka and in 1976 as an independent Faculty of Civil Engineering.

The Faculty provides high-quality education of professionals in the area of civil engineering and the related disciplines. In 2005 the Faculty commenced the Bachelor and Master degree study programs in Civil Engineering (University undergraduate and graduate studies) as well as the Vocational Bachelor and Graduate Specialist (Coastal Constructions and Infrastructure Systems) study programs in Civil Engineering.

At small and large strains, there are some areas where research is possible, and materials in which behavior is very complex. Also, our University is located in a region where landslides are very usual, especially in Istrian peninsula. So the equipment will be also used for testing landslide materials for residual behavior.

Pier Luigi Raviolo: Do you think to plan also long-term research in cooperation with other universities?

Vedran Jagodnik: I think this is possible and also an imperative. We are a small university and a small department and my opinion is that we have to connect with some more developed universities in the future. Most of the foreign universities and geotechnical departments have had this kind of equipment (or similar one) for few decades. It is not an overreaction when I say that we are a little bit behind with soil testing, but hopefully, we will start to be noticeable in near future.

Pier Luigi Raviolo: How important is it to work as a team? I mean, in addition to graduate students, who develop specific research themes and ending over three years, is there a group of engineers, professors, technicians to ensure continuity to the activity of the laboratory?

Vedran Jagodnik: Our geotechnical department consists of two fulltime professors, one adjunct professor, and one assistant professor. Also, there are four teaching assistants. Each of us is responsible for some part of the equipment. In this manner we can ensure that the entire equipment will be used as much as possible. Moreover, I have to mention that we have a very good laboratory technician, Juraj Stella, who had to learn very fast how to use all of these sophisticated equipment. In this way I think we will ensure the continuity in the activity of the laboratory.

Pier Luigi Raviolo: Dr. Jagodnik, many thanks for the interesting guidance and for answering my questions.

The visit has been very interesting thanks to the competence and detailed explanations by Dr. Jagodnik and his staff. Dr. Jagodnik added a detailed description of the different automatic equipment of the laboratory for the different types of tests and applications.

For more information: www.uniri.hr
About the Soil mechanical Laboratory at Rijeka University in Croatia

Dr. Vedran Jagodnik, Assistant Professor, Rijeka University, Croatia

**Triaxial Tests**

The Autotriax automatic system for triaxial tests in use of the laboratory, beyond the traditional standard tests, has been specifically designed to perform stress path tests, where the principal stresses applied to the soil specimen are managed independently, to replicate whichever stress conditions encountered on site. Currently a research on sandy soils is in progress: there are three medium density sand specimens under test, each inside the triaxial cell, placed on a frame, during saturation, consolidation and monotonic shear, managed automatically at the same time by a single software. One of the tests simulates the consolidation under K0 conditions: i.e. the principal stresses (vertical & horizontal) are slowly increased, in such a way to keep the cross section of the specimen constant. The software operates increasing the axial stress to a target value at a constant rate, while the horizontal stress is automatically adjusted to maintain a constant cross section of the specimen, by monitoring the feedback signal from the diameter measurement. An internal “on specimen” submersible transducer is installed for this purpose.

In order to maintain a positive contact between top cap and specimen, and to ensure correct measurement of axial force without any friction and correct axial displacement, a special vacuum type connection has been designed (Figs. 1 + 2).

**Unsaturated Soils**

Another topic of interest concerns the research on unsaturated soils and the determination of the soil water characteristic curve (SWCC). For this application the laboratory is equipped with two types of equipment:

- Double wall triaxial cell, used in conjunction with the automatic triaxial system described above
- Hydrocon SWCC apparatus, to perform consolidation tests under oedometric conditions

Both types of equipment allow tests to be performed following the principle of the axis translation method, with the use of high air entry stones: i.e. ceramic discs cemented into the base pedestal of the cell that allow water to pass through but stop air at various level of pressure.

The axis translation method consists in the application of pressurized air from the top of the specimen that will rise the pressure inside the sample from nega-
Fig. 3: Axis translation technique and volume change measurement for unsaturated soils

tive to positive values. This in turn will apply positive pressure to the ceramic disc and to the pore water pressure transducer. The difference between the air pressure from the top and the pore water pressure at the bottom is the value of suction in the specimen. The double wall triaxial cell is required for the correct measurement of volume change of the specimen (Fig. 3).

In the traditional triaxial systems, where saturated samples are tested, the volume change measurement is a simple monitoring of the water entering or leaving the sample by a volume change transducer. On the contrary, in the unsaturated systems volume change measurements are complicated by the compressibility of air. A correct measurement requires the volume of water leaving the sample and the total volume change of the specimen to be measured. With these two measurements, made with standard volume change transducers, the volume change due to water being squeezed out of the sample and, by difference, the volume change due to the compressibility of air can be determined.

In the case of Hydrocon SWCC apparatus, since the specimen is contained in a rigid ring, only the volume of water leaving or entering is required, since the total volume change of the specimen is simply measured from the measurement of the axial deformation.

Dynamic Tests
The laboratory is also equipped for the investigation of the soil behaviour under seismic actions. In these situations, that not necessarily lead to the collapse of the soil, it is important to investigate the stress-strain behaviour and the relevant parameters of the different layers of the subsoil, information required to simulate, for example, the propagation conditions of a seismic event within the ground.

The behaviour of the soil within the range of small deformations is also important in the prediction of the subsoil-structure interaction. Stiffness modules for very small deformations are now recognized as fundamental properties of the soil. Therefore the information obtained from dynamic laboratory testing are also commonly used to solve conventional problems of interaction between the building and the subsoil.

Although the level of deformation to investigate is relatively small, it is worldwide recognized that different test procedures should be applied to investigate the different levels of strain, as shown schematically in Fig. 4. For this reason, the soil mechanics laboratory of the Faculty of Civil Engineering is equipped with different equipment and testing methods, specifically designed for different ranges of strain.

Resonant Column (RC) and Cyclic Torsional Shear (CTS)
A specific apparatus, where the methods of measurements and application of stress are very sophisticated, has been developed to investigate the stress-strain behaviour of the soils, starting from very low level of shear deformation.

The Resonant Column (RC) apparatus in use in the laboratory is combined with the Cyclic Torsional Shear (CTS) and can perform experiments to define

Fig. 4: Schematic layout of deformation level related to methods of investigation

Fig. 5: Schematic view of stress conditions during CTS test
the stress-strain pre-failure behavior under cyclic load of undisturbed/reconstituted soil samples. The stress-strain parameters, like shear modulus and damping ratio are obtained in terms of curves, as functions of shear strain generally within the range of 0.0001 % and 0.1 %. These types of results are widely used for seismic response analyses at a regional/local scale.

During CTS tests, a sinusoidal torsional force at low constant frequency (~0.1 ÷ 5 Hz), for a finite number of cycles, is applied to the top of the specimen while the bottom is fixed against rotation. Torque and deformation are continuously monitored in order to obtain relationship between average shear stress and average shear strain.

In the RC test (Fig. 6), the specimen, fixed at the bottom and free at the top, is subjected to a torsional force at a frequency up to 250 Hz. The fundamental mode of vibration is found from the maximum amplitude of motion; from the resonant frequency, shear wave velocity and shear wave modulus are calculated using the elasticity theory.

**Cyclic Triaxial**

In the range of medium-high level of strain the dynamic parameters of the soil are investigated through the Dynatriax dynamic triaxial test, i.e. a type of equipment directly derived from the static triaxial, where the axial force is applied cyclically with sinusoidal pulses at constant frequency, generally ranging from 0.1 to 2 Hz.

During the tests, carried out either stress controlled or strain controlled, the stress and strain hysteresis cycles are measured and the relevant deformability pa-
Geotechnical parameters are determined (Figs. 7 to 10). The results are shown in terms of curves of the stress-strain parameters (shear modulus and damping ratio, as functions of shear strain (Fig. 11), in the same way as for RC and CTS tests but within a higher range of deformation (from 0.1 to 1+10 %). The combination of these three tests (RC, CTS and TXC) allows to investigate and define the deformability parameters of a specific soil within a complete range of deformation.

Further Standard Equipment

The laboratory includes also some standard equipment for the traditional investigation and testing in soil mechanics, for example:

- ACE automatic system for compressibility tests in oedometric cells
- Shearmatic Series automatic equipment for direct shear tests on large samples of granular soils of different density

Closing Comments

All these equipment, advanced and traditional, are by Wykeham Farrance, the Soil Mechanics Division of Controls Group, and operate with advanced monitoring systems and automatic management, data acquisition and processing, according to the relevant international standards.

Developments will certainly be in line with expectations, both in terms of scientific programs and through research cooperation with other universities already underway, that as service activities and consulting in geotechnical design.

Dr. Vedran Jagodnik is Assistant Professor and Head of the Laboratory of Geotechnics at Rijeka University in Croatia.

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Fig. 9: Hysteresis cycles of a stress controlled cyclic triaxial test – collapse of a medium density quartz saturated sand

Fig. 10: Stress path of a stress controlled cyclic triaxial test – collapse of a medium density quartz saturated sand

Fig. 11: Normalized Shear Modulus $G/G_0$ and Damping factor $D$ vs. shear strain $\gamma$
1 Aim and Problem Complex

The soil properties within the construction project area are analyzed during the planning phase. Nonetheless, it is only possible to achieve selective soil exploration even in the case of very extensive investigatory programmes. This results in a certain soil risk and uncertainties for planning and execution. As a consequence, the application of monitoring systems is becoming increasingly important in the field of geotechnics. The following structures in particular are associated with major challenges with regard to measuring anchor forces:

- Back-anchorages of long-lasting and very deep construction pits
- Construction pits in urban areas
- Slope and embankment supports for track and vehicular routes
- Port and lock structures
- Uplift control

The application of suitable monitoring systems for these particular purposes provides considerable knowledge relating to the load bearing behaviour of the soil and the ground anchor. Apart from overseeing individual construction stages, monitoring systems analyze the interaction between the soil and structure throughout the latter’s entire life cycle and safeguard the functional capability of the applied system components. Geotechnical construction projects can be adapted, optimised and carried out with enhanced safety from the information thus obtained.

Apart from the cited technical reasons for permanent anchor force measurements, there are regulations applying to standards in Section 9.1.1 of the DIN EN 1537 [1] as well as in DIN SPEC 15537 [2] for monitoring structures. They call for verification reports if deformations of load-transferring systems are anticipated, which result in substantial changes in elongation of the anchors.

2 Conventional Monitoring Systems for Anchor Force

2.1 General

There are numerous approaches for determining anchor forces of bar or strand anchors [3]. Lift-off tests and measuring with load cells, which is the commonest method, are presented in exemplary form.

2.2 Lift-Off Test

Lift-off tests provide a possibility to monitor the prevailing force in the case of strand or bar anchors. The entire anchor head structure is lifted using appropriate equipment. For this purpose, the steel tendon is prolonged or in the case of strand anchors, the wedge carrier is held by a screw-on cap so that a tensioning jack can be mounted above it. Subsequently, the tensile structure is prestressed, until the lower anchor nut or in the case of the strand anchors, the wedge carrier is lifted off from the anchor plate. Fig. 1 shows a qualitative force-head displacement diagram for a lift-off test. The intersection of the two straight lines represents the force, at which the anchor nut or the wedge carrier in the case of strand anchors lifts off from the anchor plate. Thus the inter-
section displays the actual load of the anchor. This form of anchor force control gives conclusive results but at the same time requires extensive accessories and extra personnel to execute the test. Similarly, a sufficient bar overhang must be available for a lift-off test or the wedge plate must possess an external thread or there must be a strand overhang of at least 60 cm. Furthermore, the anchor head must be freely accessible and in a position to be reached with the necessary equipment. Often lifting platforms are required for this purpose especially given high back-anchored supporting structures.

2.3 Establishing Anchor Force with Load Cells

The most common way of determining the anchor force in geotechnical applications is by means of force sensors, so-called load cells. Load cells exploit various measuring principles such as piezo technology and/or methods based on fluid pressure. Installation takes place on site. The load cell is set between the anchor plate and anchor nut or the wedge carrier (Fig. 2). The anchor force is read off analogue using a Bourdon manometer or by electric means with a digital manometer based on the system. Depending on the manufacturer and measuring principle, measuring accuracy amounts to roughly +/- 1 % if installed properly. However, practical findings have shown that given eccentric installation of the load cell or pronounced temperature fluctuations, the results can be significantly affected. In addition, in case of high anchor forces, e.g. given slope stabilisation or dam retrofitting, large, 30 to 50 kg heavy load cells have to be used. This can make installation more difficult – particularly given remote terrain or if hoisting machines are not available. Furthermore, large-sized anchor head structures represent additional obstacles for site traffic. They can be damaged and therefore no longer available for monitoring purposes. Subsequently, load cells are only suitable to a limited degree given constricted space conditions.

3 Innovative Measuring System for contactless Anchor Force Measurement

3.1 Measuring Principle

The Dywidag-Systems International GmbH developed a monitoring system for measuring the tensile load of steel tendons with Dyna Force elastomagnetic sensors. It measures contactlessly and thus counts to the non-destructive methods. Force is measured based on the elastomagnetic properties of ferromagnetic materials. The magnetic permeability $\mu$ of steel within a magnetic field changes in accordance with the mechanical normal stress state of the steel. By measuring the relative change in the magnetic permeability $\Delta \mu$ the normal stress within the steel tendon can be derived.

Fig. 3 shows the basic set-up of an elastomagnetic measuring sensor on the left. The sensor is equipped with two coils, an exciter coil and an induction coil. During measurement electric voltage is produced within the exciter coil (red). Therefore a magnetic field
is produced, which for its part induces electric voltage within the induction coil (green). The induced voltages are ultimately processed and stored by a readout unit.

The magnetic properties of a steel tendon depend on the material composition and the normal stress state of the steel tendon. This effect can be seen in the diagram contained in Fig. 3. In this case, \( H \) represents the magnetic field strength and \( B \) the magnetic flow density. The quotient \( B/H \) provides the magnetic permeability \( \mu \). Given that the hysteresis curve of a prestressed strand and a non-pretensioned strand it is shown that the change in the magnetic flow density depends on the mechanical normal stress state, the magnetic field strength or the magnetic permeability of the strand, respectively. Providing the interrelationships are known, it is possible to derive the mechanical force in the steel tendon from the induced electric voltage within it.

Prior to utilizing sensors on site the material-related relationship between relative permeability and mechanical load must be calibrated.

### 3.2 System Components

The measuring system consists of the following components as presented in Fig. 4:

- Elastomagnetic sensors
- Readout unit
- Multiplexer
- Extension cables

By means of a modem and controller it is possible to transfer the measured data. The sensors are connected to the readout unit so that the force in the steel tendon can be measured and read on the readout unit. If several sensors have to be read at the same time, a multiplexer can be installed. Extension cables are available for longer distances. To allow for cable installation a groove is cut into the anchor head structure and a cable fed through it. Subsequently the groove is filled with a sealing agent.

### 3.3 Readout Possibilities

Fig. 5 displays various readout possibilities, which can be selected according to the required application:

- In the case of alternative 1 in Fig. 5, a sensor is connected directly to the readout unit and the result recorded manually. The sensors are thus connected singly to the readout unit and evaluated one after the other.
- In alternative 2 in Fig. 5, all sensors – if need be by using extension cables – are connected to the multi-

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**Fig. 4:** Components of the measuring system

**Fig. 5:** Readout possibilities

- Alternative 1: manual readings of the measured values of a sensor from the readout unit
- Alternative 2: Simultaneous and automatic reading of all sensors via multiplexer as well as readout unit or PC on the spot
- Alternative 3: Continuously operable connection of the sensors to multiplexer, readout unit and network modem for readings from any desired location
plexer, which is connected up with the readout unit. Subsequently, the values for all sensors can be measured on the spot at the same time using the readout unit or a connected PC.

- In the case of the automatic reading system for alternative 3 in Fig. 5, the measured results are read from any location. For this purpose, all sensors are permanently connected with the readout unit by a multiplexer, which is linked to a control unit with integrated network modem. The control unit can regulate the power supply and therefore the reading interval. The results of the readings can be sent to a determined IP address by fully automatic means via the network modem.

3.4 Application Possibilities

The elastomagnetic sensors (Fig. 4, centre) are hollow formed cylinders and are assembled on the strands or bars at the factory or on site. (Fig. 6). They are installed over the strand or bar and attached in their final position by means of adhesive tape. Sensors are available in various sizes to match the different bar and strand diameters.

If the forces in the anchors are to be monitored throughout their entire life cycle, the sensors are positioned on the free length. Similarly, it is possible to mount the sensors on the bond length so that the transfer of load from the steel tendon into the soil can be examined (Fig. 7). In particular, if several sensors are attached to a steel tendon within the bond length, the course of the load transfer can be measured over the bond length. Surface friction values can be derived from the data that are gained so that execution planning can be optimised. Furthermore, the measurement results from the sensors can be applied for research purposes in order to comprehend the load transfer into the soil.

The Dyna Force measuring technique is suitable for geotechnical projects as well as for bridge construction and civil engineering. It is especially suitable for permanent structures in the case of which the development of force has to be monitored as construction progresses and during the structure’s entire period of utilisation.

The possible fields of application include:
- Back-anchoring construction pits
- Consolidating slopes and rocks
- Hydraulic and marine construction (dams, port facilities)
- Research and study projects – for example relating to construction pits and the interaction of soil and structure
- Stay-cable bridges
- Prestressed tendons for bridges and flat roofs

4 Reference Projects

4.1 The “Frankfurt Opernplatz” Construction Pit in Germany

The Dyna Force measuring system has already been used successfully in numerous national and interna-

![Fig. 6: On-site assembly of the sensors on a strand anchor](image)

![Fig. 7: Possible application positions of the sensors with the example of a permanent strand anchor](image)
ditional major projects both in the field of structural engineering as well as for geotechnical anchoring systems. The pilot project in Germany was the Frankfurt Opernplatz construction pit in summer 2014 (Fig. 8).

The excavation of the construction pit for the multistory subterranean garage is classified in the geotechnical category GK3 in accordance with DIN 1054:2010-12 [5] thus placing particular demands on the measuring system. In order to be able to check and verify the theoretical soil-structure interaction, the deformations in the construction pit lining as well as the development of the anchor forces were monitored at selected measurement cross-sections as the excavation of the pit progressed. Temporary 4-strand anchors were installed for back-anchoring purposes.

Altogether, 12 anchors were fitted with Dyna Force sensors. All measuring sensors were assembled at the factory by the Dywidag-Systems International GmbH. The sensors were packed in protective casing to prevent damage during transport and installation. Load cells were attached to the selected measuring anchors as well in order to allow a direct comparison of the measured anchor forces between the innovative measurements with Dyna Force, the measurements with load cells (Fig. 9) and the press pressure of the tensioning unit. The measured anchor forces are compared with each other in Fig. 10. Between the anchor forces obtained by the sensors and the actual anchor forces i.e. the hydraulic jack forces, a good correlation is observed. In the case of anchor B77 the anchor force obtained from measuring with load cells deviates substantially – 23.7 % – from the desired force. On account of the heavy weight of the load distribution plate for the load cell, it was not possible to position the latter centrically, thus the force established with the load cells deviated considerably from the actual anchor force. This negative effect cannot be observed when using sensors for measuring. In addition, it was determined that the sensors could be installed into the borehole unproblematically and without delay.

4.2 Grancarevo Dam in Bosnia and Herzegovina

With a height of 120 m and a width of 500 m, the Grancarevo dam in Trebinje, Bosnia and Herzegovina, is one of the biggest dams in the Balkan region. The project was completed in 1967 after eight years of construction. The dam is one of the main power and water providers for the region (Fig. 11).

During the construction phase, a slip zone was discovered in the rock on the eastern flank. Due to the dam’s arching effect, high forces were diverted into this rock. As a result, it was decided to secure the unsafe slope with prestressed anchors (Fig. 12). Knowledge of corrosion protection was, however, not so well established as it is today. At the time, the anchors were thus not covered with a corrosion protection layer but only provided with a cement stone covering. A number of
the anchors failed in recent years owing to the progress of corrosion.

As a retrofitting measure, the old anchors were removed and new electrically isolated strand anchors installed. The Dyna Force measuring system with elastomagnetic sensors is applied for permanently monitoring forces. The boundary conditions are:

- Start of project: autumn 2014
- Number of anchors: 23
- Length of anchors: 40 to 60 m
- Number of strands: 12 per anchors
- Max. test load: 2,700 kN
- Lock off load: 1,300 to 2,000 kN
- Number of sensors: 2 per anchor

The sensors were installed directly on site, prior to stressing the anchors (Fig. 13) and connected with the readout unit via multiplexers. The sensor cables were conducted from the anchor head structure via a groove in the anchor plate. All extension cables were adjusted to the required length and guided through unexposed lines. Altogether, four multiplexers and a controller were mounted so that force can be read by fully automatic means.

The controller was programmed to measure once per day. The data are secured on a server and can be read off by the responsible staff at any time. The measurement results over a period of 21 months (Oct. 2014 to July 2016) are displayed for four anchors in Fig. 14. In the case of anchors No. 17 and 23, the lock off force amounted to 1,350 kN, for anchors 16 and 18, it amounted to 1,300 kN. The forces established by the sensors proved measurement accuracy of +/- 0.5 %.

Temperatures fluctuate in the region of the dam by up to 40 °C in the course of the year. Within a few hours, differences in temperatures of 25 °C can affect the sensors on account of the south-east location. It can be seen from the diagram that the temperature or rather the temperature fluctuations exert no influence on the measurement results. This is on account of the temperature compensator found inside the sensor. Furthermore, the installation of the sensors turned out to

![Fig. 11: Grancarevo dam. Trebinje, Bosnia and Herzegovina – view of the dam](image)

![Fig. 12: Grancarevo dam – with slope secured by pretensioned anchors](image)

![Fig. 13: Grancarevo dam – installation of the sensors on the strands](image)
be highly unproblematic and straightforward. The sensors were capable of functioning in the case of all 23 anchors and provided extremely accurate measurements. Over a period of 21 months, no reduction or increase of the anchor force was measured in the case of these anchors first installed in October 2014. Similarly, the sensors had not been affected in any way.

5 Conclusions
The findings obtained so far with the Dyna Force® measuring system have shown that the system is extremely suitable for geotechnical applications as well as bridge construction and civil engineering. Compared to alternative methods for measuring anchor forces, the system possesses the following advantages:

▶ High measurement accuracy
▶ Lifelong monitoring of the prestressed tendon in structures
▶ Constant structure height of the anchor heads
▶ No additional obstacles for site vehicles
▶ Measurements in the area of the free length and the grouting section possible
▶ Fully automatic solutions possible
▶ Low intrinsic weight
▶ Uninfluenced by temperature fluctuations
▶ No additional effort for installing the anchor
▶ Highly robust sensors

Use of the measuring system up till this point has been distinguished first and foremost by straightforward
handling on site and the possibility of digital readouts of the measurement data. All measurements can be obtained centrally from a single location outside the construction pit. Thanks to the in-house production of strand anchors combined with the calibration and assembly of the sensors the high demands posed on handling can be complied with in conjunction with high measuring accuracy. Similarly, the system offers the advantage that the sensors can be arranged in the bond length so that the geotechnical soil conditions can be better understood and consequences drawn. In conclusion, the new measuring system extends the portfolio of force monitoring systems and provides advantages to enable future construction projects to be executed safely and with better quality.

6 References


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Innovative mechanised Installation of the Geosynthetic Sealing System in the Silberberg Tunnel in Thuringia/Germany

Introduction

The Silberberg Tunnel in Thuringia/Germany is 7,391 m long making it the second longest railway tunnel on the new Ebensfeld-Erfurt rail route, a part-project belonging to the German Unity No. 8 Transport Project from Nuremberg via Erfurt and Leipzig/Halle to Berlin (Figs. 1 + 2) [1]. The south portal is located on the northern slope cutting of the Oelztal valley. The tunnel dips into the Thuringian Shale Mountains and passes beneath the Großbreitenbach high plateau before encountering the mountain ridges and valleys of the Thuringian Forest. It re-emerges from the rock on
the southern side of the Wohlrosetal valley. The maximum overburden amounts to 120 m, the hydrostatic pressure up to 70 m WC.

The Silberberg Tunnel was driven by trenchless means. Fig. 3 shows the tunnel cross-section with shotcrete shell, geosynthetic sealing system and inner shell.

The geosynthetic sealing system varied with the following three versions being applied:
▶ A length of approx. 2,700 m as umbrella seal in conjunction with a drainage system
▶ A length of approx. 4,250 m as pressure water retentive single-layer all-round seal
▶ A length of approx. 360 m as double-layer pressure water retentive all-round seal given a hydrostatic pressure of up to 70 m WC


Applied Sealing Elements
The sealing system constitutes the following elements starting from the mountainside:
▶ Sealing support according to Guideline 853 [2]
▶ Geotextile protective layer made of mechanically attached PP fabric with a mass per unit area of 900 g/m² and a width of 4.00 m
▶ Geomembrane on a polyolefin basis with a width of 3.75 m and three laminated adhesive film strips as fixing element:
  ▶ 2.2 mm thick with signal layer at the airside for the umbrella seal
  ▶ 3.2 mm thick with signal layer at the airside for the pressure water retentive all-round seal
  ▶ 3.2 mm thick at the mountainside and 2.2 mm thick at the airside with signal layer at the airside for the double-layer pressure water retentive all-round seal
▶ External six-web, 500 mm wide joint strip on a polyolefin basis in keeping with Guideline 853 [2]
▶ Grouting units or connecting supports for optionally grouting the stop anchor areas of the external joint strips, the partition fields in the case of single-layer all-round seals and the chamber elements given double-layer all-round seals.

Installation
The geotextile protective layers and the geomembranes were laid mechanically in the arched area by means of an innovative laying device. The laying device can be moved to the appropriate point of installation either mounted on rails or on a crawler system (Fig. 4). It can be controlled and advanced unproblematically from the tunnel floor to accomplish the laying process (Fig. 5). The newly developed laying device was previously successfully deployed in the Brandkopf Tunnel.
The installation of the sealing system proceeded as follows:

- First of all, the geomembranes were installed in the floor area (Fig. 6) for the all-round seal.
- After completing concreting of the floor, the geotextile protective layer was rolled up mechanically by the laying device (Fig. 7) and attached to the shotcrete shell with discs.
- The geomembrane linings were also rolled up mechanically by the laying device and attached to the geotextile protective layer by means of the adhesive film strips (Fig. 8). Towards this end, the adhesive film strips were activated with hot air and fixed in place with the help of pressure rollers, which automatically provided the areas with adhesive film strips.
- The welding work, checking the welding seams and the vacuum tests for the double-layer geomembrane seals were carried out from a separate scaffold (Fig. 9).
- Acceptance tests were also accomplished from this separate scaffold.

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**Fig. 6:** Installing the geomembrane seal in the floor area for an all-round lining  
Source: GSE Lining Technology GmbH

**Fig. 7:** Mechanised laying of geotextile protective layer and attaching it with discs  
Source: GSE Lining Technology GmbH

**Fig. 8:** Mechanised laying of geomembrane lining and attaching it with adhesive film strips  
Source: GSE Lining Technology GmbH
Construction Time and Extent of Project

The geomembrane lining was laid during the period from September 2011 to December 2013. The sealed area totaled 350,000 m².

The three alternative versions of the geosynthetic sealing system accounted for the following percentage areas:

- 110,000 m² of umbrella seal with a 2.2 mm thick geomembrane
- 220,000 m² of pressure water retentive all-round seal with a 3.2 mm thick geomembrane
- 16,000 m² of double-layer geomembrane seal with 3.2 mm and 2.2 mm thick geomembrane seals at the mountainside

Findings

Positive results were obtained with the mechanised laying and the innovative fixing elements:
The roll lengths of the 4 m wide geotextiles and the 4.75 m wide geomembranes could amount to many times the existing unfolding length.

By increasing the width of the geomembranes to 3.75 m as opposed to the standard width of 2.0 m for manual laying the number of welding seams could be practically halved.

Thanks to the innovative, simple-to-install and mobile laying device and mechanised laying of geotextiles and geomembranes, the laying time was reduced significantly compared with manual laying. As a result, two formwork cars could be used with this laying device.

Even during laying activities it is still possible to access and pass beneath the laying device (Fig. 10). The fixing method using the adhesive film strips brings advantages for concreting the inner shell. Fixing by means of adhesive film is more flexible compared to fixing discs rigidly at particular points, thus resulting in errors being avoided (Figs. 11 + 12).

Mechanised laying affords advantages during the construction process with the various trades closely following one another (Fig. 13).

References


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Motivation and Background

The Meese GmbH already presented innovative fastening elements for mechanised tunnel driving and their application in the Koralm Tunnel in Austria [1, 2]. This article discusses product developments for waterproofing systems with geosynthetic sealing systems in trenchless tunnels (Figs. 1 to 3). Two aspects – inspired by enquiries from the construction industry – provided the incentive:

▶ According to codes of practice, the geosynthetic sealing system in tunnels should not be pierced. Cases such as the earthing of electric systems in rail tunnels, by conducting them from within the tunnel to the outside, still remain without a satisfactory solution.

▶ Optimisation is possible for installing tunnel furnishings such as lighting, overhead wires, signs etc. to reduce outlay and thus lower costs.

The following applications explain the advantages and latent potential of various product developments:

▶ Fastening of loads in the tunnel to the opposite side of the sealing geomembrane

▶ Earthing overhead lines in the tunnel by conducting current on the opposite side of the sealing geomembrane

▶ Shuttering guide for the efficient installation of tunnel furnishings against the inner lining
Fixing Loads on the opposite Side of the Geosynthetic Sealing System

Temporarily with the clinggo Anchor

The so-called clinggo anchor was devised to be able to fasten temporary loads in the shotcrete outer shell. As indicated in Fig. 4, the anchor consists of a round plastic sealing geomembrane shape or plate. A polyamide anchor with a threaded insert made of either M12 or M16 steel is integrated into the geomembrane to be watertight.

The Meese GmbH tested tightness at a water pressure of 5 bar and the tensile force attained by the anchor. Fig. 5 shows the test appliances used for the tightness test and Fig. 6 shows those used for the tensile test. Since the tightness test began on Sept. 26, 2014, there have been no traces of moisture and no drop in pressure observed. During the tensile tests the clinggo anchors clearly exceeded the aspired 20 kN tensile force.

![Fig. 4: clinggo anchor for temporarily fixing loads to the opposite side of the geosynthetic sealing system](Source: Meese GmbH)

![Fig. 5: Test unit for testing tightness](Source: Meese GmbH)

![Fig. 6: Test unit for tensile test](Source: Meese GmbH)

The installation of the clinggo anchor comprises the following working steps:

▶ Producing and cleaning a 16 mm diameter and 200 mm long drill hole
▶ Should the concrete quality be insufficient, reinforce the drill hole with adhesive
▶ Push the anchor all the way into the drill hole and lock in place with a jerking movement
▶ Connect the geomembrane plate by welding it onto the surrounding geomembrane
▶ Test the tensile force with anchor testing unit
▶ Screw threaded rod or shackle into the anchor and attach load in direction of anchor

Long-lasting load-bearing Element with continuous geosynthetic Sealing

A special load-bearing element (Fig. 7) serves as a connecting piece between the anchor on the one side of the geosynthetic sealing system and the load on the other side. It can be applied for structural seals in tunnelling,
Cutting is then connected to the surrounding geomembrane via welding at the construction site. Two alternative versions are currently planned for loads up to 60 kN and up to 250 kN.

**Earthing Overhead Lines**

In rail tunnels it is essential to earth the electric tunnel furnishings and for this purpose to conduct current through the geosynthetic sealing system into the shotcrete lining. The low conductivity of geomembranes represents a particular challenge in this case.

For this purpose the Meese GmbH has developed an industrially produced, standardised component with a resistance of roughly 300 Ohm (Fig. 8). It comprises a round geomembrane cutting or plate, two threaded metal contacts to attach cable lugs and a special shaped component made of conductive PE between the metal elements. The conductive PE shaped component thus possesses two functions, namely to seal against pressurised water and also to conduct current from one side of the geomembrane to the other. The individual elements are made pressure water-tight and force-fitting connected at the factory. Installation on-site is straightforward, entailing the following working steps:

- Cut a hole in the geomembrane at the point designated for earthing
- Connect earthing cables to the contacts
- Connect geomembrane plate to the surrounding geomembrane via welding

Application-specific verification of conductivity can be provided.

**Shuttering Guide**

Generally speaking, the furnishings of tunnels such as lighting, overhead wires, signs and grouting appliances are installed in keeping with a repetitive pattern. An ex-works shuttering guide for the formwork carriage for the inner lining (e.g. Fig. 3), combined with clinggo products from the Meese GmbH facilitates the positioning and installation of grouting appliances in the inner lining and avoids subsequent measuring for attachment points for tunnel furnishings and fixing points. Additionally, no further drilling is required for fixing construction components, which can cause micro-cracks in the concrete. There is a possibility that the concrete cover can also be reduced.

Fig. 9 shows the shuttering guide from the inner side of the tunnel and Fig. 10 shows the individual components in exemplary form with clinggo-spot [1, 2] and clinggo injection ports. The working steps entail:

- Cut a single hole in the formwork carriage and weld on steel bracket
- Extract the inner part and install the clinggo product, for example clinggo M16 and clinggo injection ports as shown in Fig. 10, prior to each concreting
- The clinggo product is concreted in place and remains in the inner lining when the formwork carriage is relocated

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**Fig. 7:** Load-bearing element between anchor and load with continuous geosynthetic sealing layer

**Fig. 8:** Part to earth overhead lines through the geomembrane

**Fig. 9:** View of the shuttering guide from the inside of the tunnel

Source: Meese GmbH
Fasten the parts in the predetermined position without remeasuring

**Outlook**

The Meese GmbH is currently looking for pilot projects, where the innovative and potentially cost-cutting accessories for geosynthetic sealing systems can be practically put to the test. Suggestions put forward by contractors and clients will continue to be taken into consideration for new developments. The next product is already being devised. Chances for innovations come about in particular by looking beyond the horizon, through communication and lateral thinking – beyond the bounds of construction activities as well as between construction technology, construction management and plastics technology. The Meese GmbH will readily make available its long-standing experience in plastic moulding engineering for this purpose.

**References**


Meese GmbH

As far as father and son, Ludwig and Felix Meese, are concerned creativity always starts with questioning the existing and challenging it completely if necessary. In this way, an outside perspective on processes, technologies and cycles allows the creation of entirely new solutions. Many years of experience and technical know-how from two generations of entrepreneurs, combined with level-headedness, dynamism and a mutual passion for technical innovations allow Meese ideas to function.

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**Fig. 10:** Elements of the shuttering guide displayed exemplarily with fastening element clinggo M16 and clinggo injection ports

Source: Meese GmbH


Crossrail Major Project in London – Concrete Logistics with innovative Concreting Shuttle

Dipl.-Ing. Paul Zeder, Karl-H. Mühlhäuser GmbH & Co. KG, Michelstadt, Germany

Introduction

London’s Crossrail project of the century, involving constructing tunnels totalling 42 km in length, also poses high demands on the concrete logistics during the laying of the track. The Karl-H. Mühlhäuser GmbH & Co. KG developed a project-related solution to comply with the demands set by the client. A mobile concreting system had to be provided without a locomotive but with storage and supply units, which catered for concreting in continuous operation over great distances.

The Karl-H. Mühlhäuser GmbH & Co. KG developed and produced a concreting shuttle fulfilling the high technical and logistical requirements. Making use of the company’s many years of experience and tried-and-tested components, a custom-built shuttle solution was provided composed of the following two parts shown in Fig. 1:

▶ The Buffer Shuttle for placing concrete
▶ The Concrete Shuttle for supply logistics

The first shuttle or as it is also called by the manufacturer “MCT – Mühlhäuser Concrete Train” was supplied to the site and commissioned in late-2015. This article describes the concreting shuttle, its manner of operation and its application in the Crossrail project.

Technical Description

Principle

Continuous concreting is facilitated by two shuttle units. Concrete is placed continuously underground by means of the Buffer Shuttle. The Concrete Shuttle travels between the loading station (normally on the surface, e.g. a concrete mixing plant) and the mobile unloading station (the Buffer Shuttle underground). The

Fig. 1: The “MCT Mühlhäuser Concrete Train” devised as shuttle for the concrete logistics in the Crossrail project
Source: Karl-H. Mühlhäuser GmbH & Co. KG

42 km of tunnels are being built for London’s Crossrail project of the century. An innovative concreting shuttle devised by the Karl-H. Mühlhäuser GmbH & Co. KG aids in tackling the sophisticated concrete logistics for the track installation in this major project. Here the focus is on the concreting shuttle and its manner of functioning in continuous operation. Findings obtained during its application are also explained.

Tunnelling • Construction machinery • Supplier • Concrete technology • Construction management • Major project • Innovation
Concrete Shuttle thus enables trouble-free concreting operations to be fulfilled by the Buffer Shuttle.

**Buffer Shuttle for placing Concrete**

**Components**
The self-propelled Buffer Shuttle for placing concrete in the tunnel comprises of three wagons (Fig. 2):
- Conveyor belt wagon with drive unit
- Concrete storage wagon (buffer)
- Pump wagon

**Conveyor Belt Wagon with Drive System**
The conveyor belt wagon represents an essential part of the self-propelled Buffer Shuttle, which travels over a 1,435 mm gauge track. On the one hand, it forms the interface for the installed conveyor belt with the Concrete Shuttle that provides the concrete and on the other, it contains the drive system.

The drive system comprises of a V8 diesel engine with 520 kW output and an exhaust fume cleans unit with two installed SCR (SCR = Selective Catalytic Reduction) devices. The conveyor belt wagon is provided with an operator’s cab to control the Buffer Shuttle.

**Concrete Storage Wagon (Buffer)**
The concrete storage wagon takes over two main functions in the Buffer Shuttle. Firstly, it is equipped with two self-propelled bogies, which are driven via the drive system on the conveyor belt wagon thus enabling the Buffer Shuttle to operate. Secondly, it serves as a storage unit for the concrete being processed in the tunnel. The buffer feed drum has a total volume of 52 m³ and a concrete storage capacity of 15 m³.
Two independent hydraulic circuits, which are coupled to the conveyor belt wagon’s drive system, cater for the hydraulic provision of the bogies and the drives for rotating the drum. While the bogies are operated via the two control stands on the pump and conveyor belt wagons, the rotation and the direction of rotation are set by a cable remote control – either from the pump wagon or the conveyor belt wagon allowing to control the unit from different locations. The Buffer filling level is monitored by means of load cells integrated in the base frame. The buffer drum’s filling and discharge rate depends on the given drum rpm. The buffer drum’s filling speed amounts to roughly 1.2 m³/min given maximum drum speed. The speed and direction for driving the Buffer Shuttle are determined from the two operator’s cabs on the conveyor belt wagon and the pump wagon. The speed is infinitely variable and reaches a maximum of 20 km/h for the purpose of driving. In concreting mode the Buffer Shuttle can drive at a constant speed of 3 km/h, which corresponds to a continuous concreting progress.

Concrete Shuttle for Supply Logistics

Components

The Concrete Shuttle unit which feeds the Buffer Shuttle comprises of the following components (Fig. 3):
- Combined concrete mixers (KBM12)
- Adapter wagon with power generator
- Locomotive

KBM12 combined Concrete Mixers

Two KBM12 combined concrete mixers form the core of the Concrete Shuttle. Each has a capacity of 12 m³. The two KBM12 can be combined for delivery purposes. This feature is unique on the market for such machines and essential for assuring continuous operation. In this way, a total of up to 24 m³ of concrete can be transported – also over major distances – quickly and unproblematically to the Buffer Shuttle at the point of placement and supplied at a single point on the conveyor wagon’s belt. The two KBM12 are operated by electric means via the power generator located on the adapter wagon. It goes without saying that the two drums rotate in cascade mode while travelling in order to maintain the quality of the concrete. If needed the Concrete Shuttle can be operated using only one KBM12.

Pump Wagon

The main components of the pump wagon include the concrete pump and the second operator’s cab for driving the Buffer Shuttle. The concrete discharge line transporting to the point of placement is attached to the pump wagon. Furthermore, the pump wagon possesses a cleaning unit (high-pressure nozzle with water storage tank) for smaller cleaning jobs. The pump wagon is provided with a tray to collect the cleaning water.

Driving Mode

Two independent hydraulic circuits, which are coupled to the conveyor belt wagon’s drive system, cater for the hydraulic provision of the bogies and the drives for rotating the drum. While the bogies are operated via the two control stands on the pump and conveyor belt wagons, the rotation and the direction of rotation are set by a cable remote control – either from the pump wagon or the conveyor belt wagon allowing to control the unit from different locations. The Buffer filling level is monitored by means of load cells integrated in the base frame. The buffer drum’s filling and discharge rate depends on the given drum rpm. The buffer drum’s filling speed amounts to roughly 1.2 m³/min given maximum drum speed.

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Locomotive

The Concrete Shuttle is driven by a locomotive.

The Concrete Shuttle’s Method of Operating

First of all the Buffer Shuttle – driven from the operator’s cab on the pump wagon – moves to the point of installation in the tunnel. The buffer drum can already be filled with concrete while moving into position.

Subsequently, the Concrete Shuttle drives into the tunnel. As soon as it has reached the Buffer Shuttle, concrete is transferred to the buffer drum. Towards this end, the KBM12 at the end of the Concrete Shuttle feeds directly on to the belt installed on the conveyor belt wagon. The second KBM12 feeds the first KBM12 and then supplies the conveyor belt. The buffer drum can be filled by the conveyor belt when both shuttle units are at a standstill as well as when the shuttle units are operating in crawl mode. The speeds of the two shuttle units have to be geared to one another for transferring concrete in crawl mode.

The drums can also be filled when concrete is being transferred to or from the concrete pump. The filling speed is geared to the rpm of the buffer drums regulating the pumping speed.

The concrete is transferred directly to the hopper of the concrete pump on the pump wagon. From there the concrete is pumped via a concrete line to the point of installation and placed.

As soon as the two KBM12 are empty, the Concrete Shuttle travels to the loading station on the surface to be refilled. It then travels back into the tunnel to supply the Buffer Shuttle. Depending on the length of tunnel, the MCT system can be extended by further shuttle parts to assure that a continuous supply of concrete is provided in high quality even over long distances. In this way, continuous installation rates of up to 30 m³/h can be guaranteed even given long tunnel sections.

Application in the Crossrail Project

The first shuttle called “MCT Mühlhäuser Concrete Train” was supplied to the ATC (Alstom Transport UK Ltd./TSO S.A.S. (UK Branch)/Costain Ltd.) joint venture in late 2015 and began operating at the beginning of 2016 (Figs. 4+5+6). Normally, around 100 m of track bed is concreted per day. So far the peak daily rate has amounted to 153 m. More than 50,000 m³ of concrete is to be placed by the ATC joint venture [1]. The section from Royal Oak to Paddington has already been completed (Fig. 7). Currently, the track bed between Paddington and Bond Street is being installed [2]. Since the concreting shuttle began operating in early 2016, the Karl-H. Mühlhäuser GmbH & Co. KG has provided service technicians to cater for the MCT system to run smoothly and continuously. The client, in other words, the above mentioned ATC joint venture, values the concreting shuttle as a complex system and its ability to function continuously without long hold-ups in a fail-proof manner.
Conclusion

Thanks to the MCT system comprising the Buffer Shuttle and the Concrete Shuttle, it has been possible to comply with the high technical and logistical demands posed by concreting in continuous operation in large tunnel projects.

References


Karl-H. Mühlhäuser GmbH & Co. KG

With over 150 years of experience the Karl-H. Mühlhäuser GmbH & Co. KG based in Michelstadt, Germany is famous throughout the world as one of the best-known brands for track-bound transport and trackless logistical systems as well as solutions for applying, injecting and measuring concrete for the tunnelling industry. Thanks to the many years of experience, innovation and the large variety of its products it is able to provide tailor made solutions and other support services related to all of its products.

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AIMS 2017

Objective

The key objective of the 2nd International Conference Mining in Europe is to share the latest developments on mining expertise, activities, developments and research in Europe and beyond.

The international exchange of professionals from industry, academia and governments helps to gain “knowledge to resource the future”.

Topics

The Conference will address a series of topics with a focus on

• Mineral resources
• Mining technologies
• Responsible mining

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Authors are invited to submit abstracts (up to 300 words) for possible inclusion as poster or oral presentation in the Conference program. Abstracts are to be submitted electronically via the Conference portal.

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Key Notes

Günter Becker, Munich Re.
Financial risk management in mining

Tom Butler, International Council on Mining and Metals, UK.
Improving the social and environmental performance of the mining and metals industry

Olaf Enger, MIRO.
The German pit and quarry industry

Gerd Kübler, K+S.
Challenges of salt and potash mining

Peter Woods, International Atomic Energy Agency.
Uranium resources and production
Powerful underground Cooling with the “Pressure Exchange System”

Dr. Jens H. Utsch, Siemag Tecberg GmbH, Haiger, Germany

Introduction

The opening of the new Gotthard Base Tunnel in Switzerland on June 1, 2016 was an occasion for Siemag Tecberg GmbH, a German mining technology company, to review a very interesting project. In connection with this project, hoisting technology from Siemag Tecberg was delivered and the shaft hoisting plant to provide the middle section of the tunnel site was operated during the whole construction period [1, 2].

Furthermore the company was also involved with an interesting technical solution as part of the underground cooling system. At a significant point involving the cooling plant for the tunnel site a so-called Pressure Exchange System (P.E.S.) of Siemag Tecberg GmbH was applied [3]. The mode of operation and the significance of this patented product as an essential part of an underground cooling system with a central cold production plant on the surface are described in this article.

Mining Industry – a Challenge

The development of the mining industry is characterised on the one hand by penetration at greater depths and on the other hand by advancing mechanisation. Both developments result in increasing demands on cooling and ventilation of the mines.

Also in geographical areas with extremely low temperatures on the surface, high rock-temperatures of about 50°C are possible underground. In the event of lower rock-temperatures of roughly less than 30°C, higher underground air temperatures can affect the operating of machines thus require climatisation.

Alongside the shaft hoisting plant to be understood as the essential element for supplying a mine, the climatisation also has great significance for its operation. As a result, cooling and ventilation are not merely a question of efficiency but depending on particular conditions cooling and ventilation are significant for safety and health at the workplace.

The Concept of central Cold Production on the Surface

Different concepts are conceivable for cooling a mine. The cold production is generally feasible on the surface as well as underground.

Underground cooling plants with refrigerating machines are characterised by several disadvantages compared to central cold production on the surface. The erection of refrigerating machines underground requires additional caverns. Maintenance and repair jobs are more expensive than in case of refrigerating machines on the surface. Underground refrigerating machines are vulnerable to dirt, which decreases the efficiency of the refrigerating machines. The demand for re-cooling on the surface for underground cooling machines requires shaft-pipes to transport the warm water from underground to the surface. This generates a significant heat input for the shaft. Furthermore, the underground cooling machines need firedamp protection. All these disadvantages can be avoided through a central cooling plant on surface.

In case of a central cooling plant on the surface the generated cold water is transported underground by the inlet flow of the so-called primary circuit to provide coldness underground; with the outlet flow of the primary circuit the heated water is transported from underground back to the cooling plant on the surface to become cold again. The exchange of the cold temperature underground is carried out between the primary circuit and the secondary circuit. In the case of the secondary circuit, the air coolers are provided with cold enabling them to reach the target air temperature. After this temperature exchange (between water and air) the warm water flows back, again for temperature exchange between secondary circuit and primary circuit.

Conventional Cooling Concept

In conventional concepts, both circuits flow in a heat exchanger alongside each other and exchange the temperature; i.e., the cold water from the primary circuit exchanges the cold temperature with the secondary cir-
The advanced concept with a P.E.S. is different. The P.E.S. does not merely exchange temperature (energy); furthermore the cold water coming from the surface is exchanged with the warm water from underground. The cold water reaches the coolers by the secondary circuit and flows back to the cooling plant on the surface. The principle of the P.E.S. is similar to a pressure lock. The structure and the mode of operation are explained in detail below.

**Advanced Cooling Concept**

The advanced concept with a P.E.S. is different. The P.E.S. does not merely exchange temperature (energy); furthermore the cold water coming from the surface is exchanged with the warm water from underground. The cold water reaches the coolers by the secondary circuit and flows back to the cooling plant on the surface. The principle of the P.E.S. is similar to a pressure lock. The structure and the mode of operation are explained in detail below.

**Structure and Mode of Operation of the “Pressure Exchange System”**

The Pressure Exchange System was developed bearing the German name “Dreikammerrohraufgeber”, in English “three chamber pipe feeder”. This description demonstrates that a P.E.S. consists essentially of an arrangement of three horizontal pipes, so called “pipe chambers”. Both outlets are connected each case with two vertically arranged distributor pipes (Fig. 2). Via one of these vertical distributor pipes the three pipe chambers are connected with the primary circuit, via a second of these vertical distributor pipes the chambers are connected with the secondary circuit. Valves at the connection point between pipe chambers and distributor pipes have the function to connect the various pipe chambers either with the primary circuit or with the secondary circuit.

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**Fig. 1:** Central cooling plant with a P.E.S.
Source: Siemag Tecberg GmbH

**Fig. 2:** P.E.S. – Connection of the pipe chambers with the vertical distributor pipes
Source: Siemag Tecberg GmbH
During operation each pipe chamber changes from the processing stage to processing between three different operating states:

(A) Fill up the pipe chamber with cold water and transport the warm water back to the surface via the primary circuit
(B) Central Pressure equalisation of the chamber which is filled up with cold water
(C) Fill up the pipe chamber with warm water and transport the cold water underground via the secondary circuit

Should a pipe chamber be connected with the primary circuit by the appropriate valve position (Fig. 3, chamber A), it is filled via this circuit with cold water from the cooling plant on the surface; the warm water, fed in by the previous operating step before, is expelled by the inflowing cold water and transported via the return flow of the primary circuit back to the cooling plant on the surface. This transport of the warm water to the surface takes place by the principle of communicating vessels: By the inflow of cold water into the pipe chamber there is high hydrostatic pressure coming from the vertical height between the cooling plant on the surface and the P.E.S. underground affecting the transport of the warm water to the surface. There is a small loss of capacity caused by frictional losses of the pipes. Owing to the high pressure of the primary circuit this circuit is also called a high pressure circuit.

The P.E.S. as interface between the two circuits connects one with the other and enables the circuits to operate with different pressures. The therefore necessary pressure exchange occurs in operating state B.

Meanwhile one pipe chamber is in operating state A, the valves of a second pipe chamber, previously filled up with cold water, were closed (operating state B). Only smaller valves, connecting the pipe chamber via bypass-pipes with the secondary circuit, are opened. In this manner the high pressure resulting from the previous operating state (inflow of cold water from the surface), is decreased. This pressure exchange is necessary to protect the system against shock pressure and damage to the pipes, to be expected if the main valves were opened without pressure exchange; in this case, the high pressure of the pipe chamber, filled with cold water, would suddenly meet the significantly lower pressure in the pipe of the secondary circuit.

The third pipe chamber of the P.E.S. meanwhile is connected with the secondary circuit (operating state C). Via the secondary circuit assisted by a pump the cold water from the pipe chamber is transported to the coolers after the pressure exchange. According to the cycle-effect for the same time the water heated by the coolers flows back to the pipe chamber of the P.E.S.

In this manner, each pipe chamber is translated from one step to the next according to the valve position and pass through all the three operating states. Operation with three chambers enables the ongoing circulation in both circuits.

**Advantages of the “Pressure Exchange System”**

The operating mode of the P.E.S. is characterised by the three following functional principles:

► Exchange of the circulating water in the circuits
► Principle of the communicating vessels
► Pressure exchange of the two circuits

The essential advantage of a cooling plant with a P.E.S. compared to alternative solutions is founded on the principle of the exchange of the circulating water. Based on the fact that the cold water flows via the primary circuit into a pipe chamber and is transmitted into the secondary circuit a short time later, the loss of water temperature is less than 0.5 K [4].

The alternative concept for comparison is – as explained before – a central cooling plant with a high pressure-low pressure heat exchanger instead of a P.E.S. on the surface between primary circuit (high pressure circuit) and the secondary circuit (low pressure circuit). Both concepts are similar concerning the other components. Basically plants can indeed be equipped with a plate heat exchanger. As these devices cannot be stressed at such high pressure, plate heat exchangers are only realisable at lower depths. In these fields of application cooling plants with a P.E.S. are mostly not a viable solution for economic reasons. Even if each case has to be judged individually with respect to several parameters, the competitiveness of a solution with a P.E.S. decreases at depths lower 200-300 m.

Because of the increasing hydrostatic pressure according to the depth, where a P.E.S. is of economic in-
terest, the competitive solution vis-à-vis a P.E.S. would be a high pressure-low pressure heat exchanger. Seen in economic terms, a solution with a P.E.S. is to be preferred, if the higher purchasing are offset by operational efficiency advantages.

On account of the lower temperature losses of approx. less than 0.5 K as opposed to more than 2-3 K in the case of heat exchangers, a system with a P.E.S. needs less energy to produce coldness and also less power for pumps, because the water flow through the system is less.

**Findings**

The Pressure Exchange System, fascinating because of its simple idea, has been applied since it entered the market in more than 30 projects, mostly for mines but also several tunnel projects, for example, the new Gotthard Base Tunnel.

The delivered plants are characterised by constant lifelong efficiency and low maintenance downtime. A further advantage is the low amount of space required underground.

The dimensions of cooling plants with P.E.S. systems, as measured by the power, range between 4 and 60 MW. The biggest cooling plant with 60 MW for a 2,400 m deep gold mine in South Africa involves four connected P.E.S. systems, shared on two levels (−1,200 m and −2,400 m) [5].

These examples of realising single plants between 4 and 20 MW as well as the possibility to implement big cooling plants by combining several P.E.S. systems show the variability and adaptability as well as the gradual extensibility of a P.E.S. system. The extensibility (as well as the reducibility) of a system enables the P.E.S. system to be adapted according to the development of the mine because changes have to be expected during their life cycle.

So far, applications have not been particularly numerous in tunnel construction, e.g. the Gotthard Base Tunnel. But these sample applications show that the P.E.S. technology primarily developed for mining is also useful in tunnelling. In this sense Siemag Tecberg is also anxious to develop solutions for underground cooling in future for tunnel construction.

**References**


**Dr. Jens H. Utsch**

Studied construction engineering and business sciences at Kassel University. He gained his doctorate at the university’s Institut für Bauwirtschaft in 2007 and subsequently was active as project manager and lecturer. Since 2009 he has been with Siemag Tecberg. Initially involved on the permanent disposal sector, for the past year he has been project manager in the field of underground cooling.

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Powerful underground Cooling with the "Pressure Exchange System"
Research Project “Mining-RoX” – From 3D Mine Scans to a Mine Rescue Simulator

Thomas Schmieder, Cinector GmbH, Mittweida, Germany

Motivation

Virtual training simulators are being deployed in numerous fields, from pilot training and digital driving lessons to military simulations. With the notably high security standards in Germany and many other countries, thorough preparation for the case of danger becomes imperative.

Virtual simulations as training environments provide multiple inherent advantages: a simulation is safe, repeatable, observable and configurable. Especially the preparation for dangerous situations, during which operational and rescue personnel have to make correct decisions under immense pressure and a complex chain of action needs to be followed, requires regular repetition. This priming may save lives in the end.

The Mine Rescue Simulator is such a tool, trying to assist the men and women that risk their lives underground for the safety of others. As such, the functional prototype is to be expanded to more accurately represent real circumstances. This includes the option to create new mines from structural blocks in order to prepare the mine rescue crews for their deployment in unfamiliar mines. Those basics may later very well be applied to other fields.

Description of the innovative Simulator

The prototype of the Mine Rescue Simulator came into being through “Mining-RoX” a cooperative research project of TU Bergakademie Freiberg and Mittweida University of Applied Sciences [1]. It is based on the Cinector Engine, the real-time engine of the Cinector GmbH, which is otherwise primarily utilized in 3D media production software.

It is a training simulation based on a gamemaster principle. The instructor sets environmental parameters and specifies during the simulation how that environment reacts to player interactions. The training scenarios currently include fire, dangerous gases, and missing persons.

Training lessons can be absolved by a team of up to five participants, the usual strength of a mine rescue squad. By logging interactions and communication, this allows for conducting, repeatable training scenarios within the safety of a virtual world. This reduces the necessity to execute complex and costly training sessions in real mines and also provides the opportunity to approach extreme scenarios, which would otherwise be impossible to emulate. The simulator does not demand special hardware. The system runs on normal PC hardware (six notebooks connected via Wi-Fi).
Experiences with Virtual Security Training using the Simulator

Utilizing the prototype during basic training for the TU Bergakademie Freiberg student mine rescue program yielded very positive results. The training instructors attested to its efficacy and influence on the subsequent exercises above and below ground. According to Prof. Helmut Mischo, Chair for Underground Mining Methods, using the simulator improved the participants’ communicational skills and decision-making abilities [2].

Outlook

In future the simulator and its upcoming iterations shall be integrated into the training and educational program at TU Bergakademie Freiberg, as well as with other companies, institutions, and scenarios.

References


Key Data of the Prototype Mining-RoX Mine Rescue Simulator

- PC application, controlled with mouse and keyboard (potential extension to virtual reality headsets)
- five training participants and one instructor
- Interactive equipment: oxygen display and gas meter
- Several more pieces of equipment (first aid kit, fire extinguisher, etc.)
- Environmental factors: gases, smoke, fire, persons, obstructions, instability
- Logging: environmental parameters, interactions with the environment, communication
- Exercise environment: reconstruction of a real mine stretch of Reiche Zeche in Freiberg (based on 3D scan data of Mining-Rox as well as CAD data)

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Fig. 3: Virtual security training – basic training in the TU Bergakademie Freiberg with students
Source: Cinector GmbH/Hochschule Mittweida
GeoResources Zeitschrift and Journal
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