INTRODUCTION OF THAILAND UNDERGROUND & TUNNELLING GROUP (TUTG), EXPERIENCES AND CHALLENGES IN UNDERGROUND ENGINEERING IN SE ASIA

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EVALUATING THE CRACKING POTENTIAL OF SHOTCRETE

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OPTIMIZED SHOTCRETE DESIGN FOR IRREGULAR TUNNEL EXCAVATION

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STEELFIBRE FOR HIGH PERFORMANCE SHOTCRETE, THE WAY TO MORE COST EFFICIENCY

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This paper shows the relations between costs and time of high performance products and process optimazing. Owner and at least contractors are under permanent cost and time pressure. The experiance in the shotcrete pumps and machine are in a high level in case of volume and performance. However looks the contractor for more value engineering too save money and time. The important step is to change the established way and optimazing the process to more efficiency. The ready mix are fast, well applicable and the end result of the concrete is allways in a good or high quality. Steel fibre manifacturer optimaze theirs steel fibers to high performance products, with 2’200 Mpa. The compination of high performance concrete and high performance steel help to minimazing time consuption and abrasion in pipes, pumps and nozzle.

Invitation of bids take the wording of standarts and guidelines, that’s meaning they need 30 kg/m^3 steelfibers for 700 J in the apsorbtion test. High performance fibre take more than 1800 J with this dosage rate. The involved parties must work together to fund the cost and time effective solution.

The presentation show the audiance the technical frame, the way of development for the using on the sites with differnet samples. The steps to develop the end redymix are sometime theoretical and some more empiric. But allways we need less fibre (<40% for) the same performance.

The presentation show us the handling of the requirements, basis, standarts, guideline and more form designers view, the contractors view and the owners view. How we manage this and how big the result of this is.

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WATERPROOFING SOLUTIONS FOR TUNNELS

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DESIGN OPTIMIZATION AND APPLICATION OF BOLT-SHOTCRETE SUPPORT FOR EAST TIANSHAN TUNNEL PROJECT IN CHINA

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Key Words: bolt-shotcrete support; optimization of support design; structural mechanics characteristics; field application

Bolt-shotcrete support is a form of support with low cost, convenient for construction, uniform structural stress, which is widely used in international tunnel engineering. In this paper, the 2# inclined shaft of East Tianshan tunnel in China is taken as the research object. The stress characteristics of composite lining support and bolt-shotcrete support are analyzed and compared by FLAC^{3D} software, and the bolt-shotcrete support scheme suitable for this project is put forward. Based on the principle of orthogonal experiment, the most reasonable shotcrete material proportion is selected, and structural stress and displacement monitoring is carried out during the construction stage of typical sections. The results show that: (1) in FLAC^{3D} simulation calculation, the interface element is applied between different layers, which can simulate the interaction between different layers of lining structure and reflect the mechanical characteristics and displacement characteristics of the interface between layers; (2) from the aspect of mechanical performance, single layer lining which can meet the requirements of tunnel support with thinner structural thickness and has higher economic efficiency, is better than composite lining; (3) the field monitoring results show that the deformation of bolt-shotcrete support structure is small, the structural stress meets the material performance requirements, and there is no structural damage during the construction of the test section; (4) during the implementation of bolt-shotcrete support, the cost of support per meter is reduced by 36.78%, and the average excavation efficiency is increased by 38.9%, which verifies the applicability and advantages of the optimization scheme. The research results in this paper can provide reference for the follow-up construction of tunnels and similar projects.

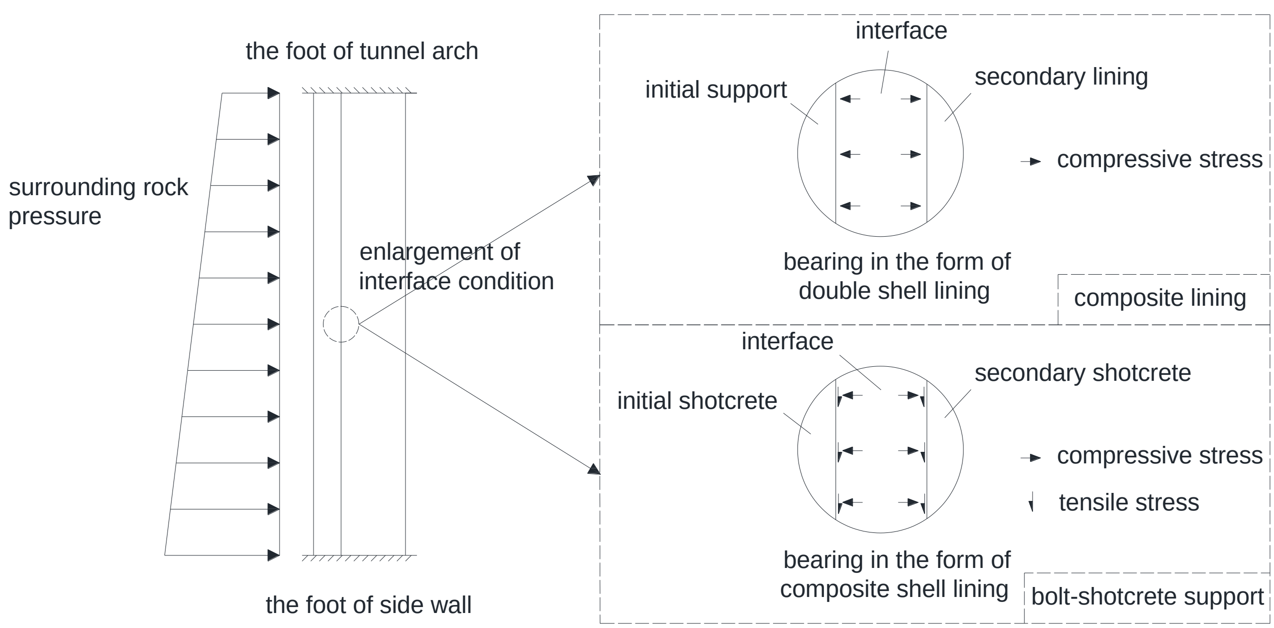

Figure 1 – Schematic diagram of bearing mode of side wall under different structural forms

PERFORMANCE IMPROVEMENT OF SHOTCRETE BY POLYMER BINDER MODIFICATION

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Key Words: Shotcrete, Polymer-Binder, Water-Tightness, Field Report, Rebound.

Tunneling construction engineering cannot exist without sprayed concrete – whether it is in tunneling, mining or equivalent constructions. Underground construction is a vast field and will be of strategic urban importance in the future. On the one hand, many existing tunnels will need in short term repair work or enlargements, while there is huge demand for the construction of new ones.

Polymer-modified sprayed concrete is suitable for the most used wet shotcrete application, but, as it is also common to use dry shotcrete, it's also possible to be used there.

The used polymer amount depends highly on the requirements, in terms of the levels of strength, stability and water impermeability. The application of modern shotcrete needs to reduce rebound from the spraying, which is a time, cost and environmental factor due to the loss of material and changes of concrete properties, and polymer-modification is an interesting possibility to achieve the target. Modifying sprayed concrete with polymers reduces material consumption and improves spraying efficiency and durability.

The technical performance of wet or dry sprayed concrete demonstrated and measured under real application conditions proved the positive effect of polymers in sprayed concrete.

A description of review of field tests and reference projects will be provided, an overview of possible applications, usage and advantages where polymer-modified sprayed shotcrete was applied.

- At a salt mine wet sprayed concrete was used, reported earlier in Davos in 2009, when groundwater seeped into the middle of the tunnel. By modifying the regular concrete formulation with polymer binders, the processing was secured, a 10 year field report.
- At the Hagerbach test Gallery, a field test with wet shotcrete proofed the water tightness performance.
- At a pressure water tunnel logistics were critical for project realization, and the reduction of rebound – realized with dry sprayed concrete – improved the project's progress.
- At a water canal polymer modified dry sprayed concrete was used to strengthen the flanks against elevated water pressure.

MEANINGFUL TESTING OF FIBRE REINFORCED SHOTCRETE FOR LINING DESIGNS

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Key Words: macro synthetic fibre, fibre reinforced shotcrete, panel testing, beam testing, lining design

The routine use of Fibre Reinforced Shotcrete (FRS) as an integral component of ground support systems is well-established. FRS, employing steel or macro synthetic fibres, is used worldwide in service conditions ranging from low stress friable ground to high stress hard rock, and over a wide range of exposure conditions, often harsh, such as at high temperature, chemically aggressive ground or waters, static stresses and dynamic loadings, etc.

Shotcrete linings require a rotation capacity in order to follow ground movements while the arching effect in the surrounding rock mass develops. The fibre reinforcement within the shotcrete overcomes the brittleness of concrete and provides the necessary ductility after the shotcrete cracks, to prevent a sudden failure. The ductility or toughness provided by the fibres is determined by experimental testing.

Testing of FRS is carried out either routinely, as a mechanism in establishing quality control in an ongoing project, or when dedicated testing is required to confirm efficacy, properties and performance levels of FRS proposed for use in a system or application. For test results to be meaningful to the assessment of performance it is of vital importance that the test methods employed are reliable, repeatable and relevant.

Two types of test methodologies are standardized and in use, i.e. beam tests and panel tests. When evaluating FRS it is very important to use a test methodology that is at least representative of the loading mechanism, the load-bearing mechanism and reflects the full capabilities of the FRS. Beam tests are low deformation test (up to 4mm) and so cannot adequately represent larger deformations that can be found in typical underground environments. For sprayed concrete linings, panel tests, which measure energy absorption, are the more relevant test methods to represent a shotcrete lining failure mechanism. Panel tests are statically indeterminate (hyperstatic), just as the shotcrete lining itself is, and thus, represent the structural behaviour of the lining best.

This paper discusses the commonly employed standardized test methods for fibre reinforced concrete and shotcrete, examines the referring results, and discusses how those results are interpreted. Further, it informs how those results can be influenced by external factors and exposes the potential of some results to misinterpretation.

The aim of this paper is to assist those currently assessing FRS in existing ground support systems and those developing new systems in understanding which testing is “meaningful or meaningless” in its capacity to provide data employable in ongoing systems assessment, or in the selection and nomination of values required in developing efficient, safe, economical and durable FRS mixes in new works.

SHOTCRETE OF THE OUTER SHELL AND THE SEALING SYSTEM

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PUMPING SHOTCRETE: PAST KNOWLEDGE APPLIED FOR MODERN SHOTCRETE MIX DESIGN

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UNTERSAMMELSDORF TUNNEL – CHALLENGES, SPECIAL MEASURES AND USE OF SPECIAL SHOTCRETE DURING TUNNELING IN LACUSTRINE CLAY

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Key Words: conventional tunneling, special construction method, jet grouting, shotcrete, soft ground

The 665 m long, twin-track Untersammelsdorf Tunnel is being built in the course of the construction of the Koralmbahn line between Graz and Klagenfurt. The tunnel is located in extremely challenging subsoil conditions consisting of silty to fine sandy lacustrine deposits. The developed tunneling concept provided wide-ranging special underground engineering measures as piling, jet grouting and temporary struts and represents a unique construction method to date. Accordingly, numerous challenges arose in the design phase, which could be verified by carrying out extensive trials and investigations in the preparatory period or for which fallback levels had to be provided for the support system.
In order to guarantee the stability of the face, two to four jet grout columns were provided at a longitudinal spacing of 2.03 m (see figure 1).

Figure 1 – Heading face

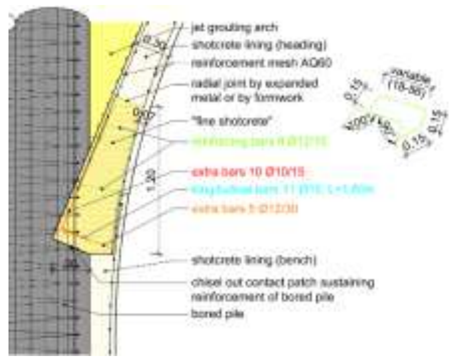

Figure 2 - Detail of the notch in the bored pile to support the primary lining

A challenge was the transfer of vertical forces from the jet grout arch into the bored piles due to the lack of reliable parameters for friction and cohesion forces in the joints between jet grout body and bored piles. Therefore load transfer from the shotcrete lining through notches in the bored piles was provided as an additional measure (see figure 2). In order to transfer concentrated loads through a relatively small area, technically correct construction according to the design of the shotcrete lining in the notch was essential. But precisely here in the bearing area there was a danger of honeycombing due to rebound and spraying through several layers of reinforcement. Therefore a special shotcrete has been developed and testiest in extensive trial spraying.
As the bench and invert were advanced, the 10 to 12 m long unsecured excavation area represented the critical loading case for the bored piles at the sides. In order to avoid heavy bending reinforcement in the bored piles, dewatering boreholes were drilled to reduce water pressure acting from outside and temporary bracing between the bored piles was planned in some sections (see figure 3).
Now tunneling work is complete, the experience can be reported.

Figure 3 - Bench and invert excavation with temporary bracing between bored piles

3D TUNNEL INSPECTION WITH PHOTOGRAMMETRIC AND HYBRID SYSTEMS

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Key Words: Tunnelling inspection, tunnel monitoring, damage detection, highspeed tunnel surveying

The trend in tunnel assessment is towards comprehensive 3D measurement, either based on high quality digital imagery (photogrammetric systems) or the combination of laser and photo systems (hybrid systems). With digital 3D data, quantification and categorization of damage to the tunnel surface as well as the determination of thickness or volumes of layers (e.g. shotcrete) can performed in a comprehensive, fast and economic way.
The faster such tunnel assessment can be executed on site, the lower are the tunnel block times and environmental impairments related to the building measures. The costs for the operating companies can be significantly reduced as well as the personnel efforts and risks of accidents. Furthermore, tunnel safety is increased due to faster test cycles which result in a more comprehensive overall monitoring.
Dibit has developed two photogrammetric 3D measuring systems for tunnel inspections with a continuous movement. One system is pushed by hand and reaches a walking speed of around 2 mph. The other system, operates at a speed which is unique worldwide:

- The 3D surveying system can record the tunnel with high quality in terms of geometry and detail at a speed of up to 50 mph (Figure 1).
- The system uses state-of-the-art high-speed industrial cameras and a specially developed flash technology to illuminate the (predominantly dark) tunnel structures.

Both dibit systems enable up-to-date tunnel inspection:

- The photorealistic texturing of the 3D model enables the identification and analysis of even the smallest material damage (e.g. cracks <0.3 mm wide; Figure 2).
- The 3D tunnel data and measurements of tunnel objects (cracks, damaged areas, installations, thickness and volumes of shotcrete layers etc.) can be managed in the database Dibit-TIS (Tunnel Information System), which is the “proto”-BIM (building information modeling) for tunnel applications.

The presentation introduces the technique of the 3D measuring systems of dibit and illustrates the quality of the measurements based on conducted projects.

Figure 1 – Highspeed 3D system mounted on a crane

Figure 2 – Tunnel damages analyzed in software “Dibit

STABILITY ANALYSIS AND REINFORCEMENT OF THE EXISTING KARST CAVE PASSING THROUGH YUJINGSHAN TUNNEL

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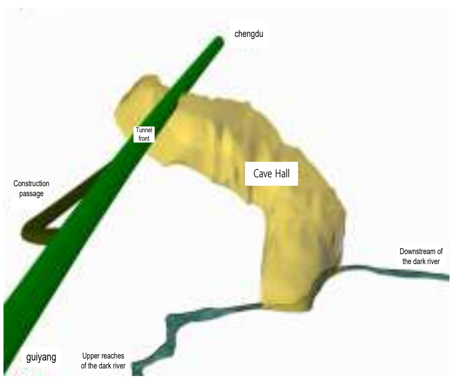
Key Words: High-speed Railway; karst cave ; shotcret; grouting; case

High-speed Railway tunneling in karst terrain presents a huge challenge to the engineer including the identification, stability analysis and reinforcement of the karst cavities. The Cheng-Gui high-speed railway tunnel had to pass through the largest karst cave discovered in tunnel construction. To guaranteeing the tunnel construction safety, a series of corresponding prevention and control measures are put forward. To begin with, geological drilling, electromagnetic method and surface electrical resistivity tomography are adopted to detect and delineate the underground karst zone. Based on the detection results, this paper has put forward strategies to make the pre-support of karst cave and the main technical of those strategies include: the side-walls or in the crown was applied with shotcret (C40 steel fiber concrete); use expanding-shell pre-stressed hollow anchor rod and pre-stressed cable reinforcement; fix steel-mesh-bolting; the shotcrete sealing was applied. Moreover, if instabilities would develop in the side-walls, it should be sufficient to stabilize the cavities, to do dental cleaning of the broken rocks, and fill the voids with shotcrete or pumped lean concrete. At last, systematic grouting treatment around the excavated section, and was excavated with the layer-step method. The solutions presented here may provide guidance for the design and construction of high-speed railway tunnels to be implemented affected by karst processes. The technical validation of the proposed solutions was demonstrated by the successful completion of the Yujingshan tunnel.



PLASTIC SHRINKAGE PROPERTIES OF NATURAL FIBER REINFORCED SHOTCRETE

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Key Words: shotcrete, plastic shrinkage, natural fiber, early age

Recently, natural hemp fibers have been developed for use in wet or dry mix shotcrete instead of conventional synthetic fibers made from petroleum. Synthetic fibers, which is mainly in polypropylene, has been used for controlling an initial shrinkage cracking in concrete, however, the effect was poor showing a severe plastic shrinkage cracking.

Plastic shrinkage cracking is a nonstructural crack that occurs due to the surface drying of concrete in a plastic condition due to rapid evaporation of bleeding water. The volume reduction due to plastic shrinkage and the resulting tensile stress exceeds the tensile strength of the concrete. In particular, plastic shrinkage cracking occurs mainly in large surface area members. It may be evolved from the surface to a considerable depth, or in the case of a very thin structure, it may go all over the depth of the member. In addition, since it is long enough to be easily distinguished by naked eyes and cracks are generated widely, it is not aesthetically pleasing and anxiety about the stability of the concrete can be increased. Also, the plastic shrinkage crack accelerates penetration of chloride and moisture, causing corrosion of the reinforcing bar, and durability of the concrete is lowered.

The theoretical effect of natural fibers on plastic shrinkage cracks is that when natural fibers are mixed into concrete, they become wet by absorbing the water. Then, in the pumping, water in the wet natural fiber is supplied to the concrete by the pumping pressure to increase the pumpability. Re-absorbing the water after spraying increases the adhesion and build-up thickness. The absorbed water could be supplied to the shotcrete and resulted in reducing a plastic shrinkage and dry shrinkage. This paper investigates the plastic shrinkage properties of shotcrete containing natural fibers. A series of experimental program were conducted to analysis the theoretical background and to select the optimized natural fiber content.

DEVELOPMENT OF A SPRAYABLE GEOPOLYMER CONCRETE FOR FIRE PROTECTION IMPROVEMENT AND UPGRADING OF UNDERGROUND TRAFFIC STRUCTURES

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Keywords: Sprayable geopolymer concrete, fire protection coating, concrete spalling

The existing tunnel structures in Germany are characterised by progressive ageing, which is particularly evident in the tunnels' inner lining. In addition, under the influence of incisive events and new research results over several years, the government has reviewed and updated some of the guidelines under which these buildings were designed and constructed. If this deterioration now requires the repair of a building, the new requirements must be taken into account. This can sometimes lead to a considerable increase in the requirements for operational safety, durability, resistance, or structural fire protection.

In the German research project KOINOR, a sprayable geopolymer is being developed which should fulfil the requirements for a tunnel lining of the new guidelines. The focus here is on high fire resistance as well as high resistance to other concrete-attacking substances, such as chlorides or sulphates. This publication presents the first results on the applicability of a sprayable geopolymer concrete. Therefore, investigations of the geopolymer application process and its fire loading material properties are now being discussed. First fire tests are also hinting towards a substantial fire resistance and no spalling issues with this new material at all, which could help with a lot of current problems of traffic tunnels in general and road tunnels in special.

INVESTIGATIONS REGARDING THE PUMPING PROCESS OF WET-MIX SHOTCRETE

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Key Words: Shotcrete, wet-mix, pumping pressure, rheology, Sliper, filter press, high-speed camera.

Workability is a physical property of fresh concrete, which can’t be described with only one single parameter or measured with one single test method. Pumpability and sprayability plays an important role for wet-mix sprayed concrete. The material must be conveyed through the pipe without changing its properties and mix proportion. The mix should leave the nozzle in a uniform stream intermixed homogeneously with the accelerator.

When concrete is pumped through a pipe, a thin layer of paste is lubricating the wall of the pipe. The interaction of the lubricating layer and the pipe wall is of great importance for pumpability. The shear of the layer allows the slipping of the concrete and leads to a reduction of the required pumping pressure. In this presentation a sliding pipe rheometer “Sliper” is used to determine the pumping capacity of concrete. The Sliper consists of a pipe and a guided piston which is standing on the ground. A pressure sensor is integrated onto the piston. When the pipe is sliding downwards, the pressure in the pipe as well as the speed of the pipe are recorded. Rheological parameters as well as the supposed pumping pressure may be estimated.

The cohesiveness of concrete is important to avoid blockages in the conveying pipe. Blockages can occur, when the paste separates from the aggregate skeleton because of a high pressure in the pipe. The stability of the wet-mix was determined by a filter pressing test.

Mixes tested by the Sliper and the filter press were then sprayed with a wet-mix shotcrete machine Sika PM 500. This machine was equipped with seven pressure sensors, which could monitor the pressure over time. The sensors measured the pressure of the hydraulic system, the mix at the beginning and end of the pumping line, the pressure of the accelerator shortly after the pump and at the end of the hose, the pressure of the air and finally the pressure in the aerosol converter.

Simultaneously, the spraying was filmed by a high-speed camera. This slow-motion recording shows the homogeneity and pulsation of the spray jet. At its best, shotcrete should emerge from the nozzle in a steady, uninterrupted flow.

Different durable and sustainable mixes, developed under the Austrian research project ASSpC, were sprayed at different output of the shotcrete machine. The results and lessons learned from the results will be final part of the presentation.

GEOLOGICAL 3D ANALYSES OF TUNNEL FACES WITH SOFTWARE AND HARDWARETOOLS OF DIBIT

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Key Words: Tunnelling, geology, software, tunnel face, 3D reconstruction

The measurement and visualization of tunnel structures is the main competence of Dibit Messtechnik GmbH (Innsbruck, Austria). As the inventor of modern 3D tunnel surveying at the end of the 1990s, Dibit is a leader in global surveying projects and develops innovative software and hardware tools for geological applications in tunnelling.

In tunnel construction, the trend is towards the comprehensive, digital 3D recording and mapping of tunnel faces, especially to measure and quantify geological structures, and to document geological conditions. This must be done under the pressure of time and the harsh conditions of progressive mining and result in objective, reproducible data. On the one hand, these data should permit a standardized assessment of the rock conditions and on the other hand they should be analysed, archived and virtually viewed in a digital workflow.

At the 2nd tube of the Perjentunnel at the S16 Arlberg Expressway ILF Consulting Engineers has been responsible for the geologic documentation and Dibit for the geotechnical measurements. For described reasons Dibit has developed a geological 3D recording and analysis system, which is unique in this form. The system has been supported and tested by ILF during the excavation works in 2018. It consists of three main components:

1) Photogrammetric 3D recording unit "Handheld": With this compact and robust device, the tunnel face is recorded or measured in just two minutes (Figure 1).
2) Geological annotation software "geological tool": The software is used on a tablet computer in-situ for the geological assessment of the tunnel face. The recorded lithologies, microstructure measurements and rock characterization are incorporated into the processing of the 3D model (Figure 2)
3) 3D analysis software "Dibit": With the software, the 3D reconstruction of the tunnel face and the further analysis of structural, rock and geometric features is done.

With the system, geological investigations of tunnelling can be carried out very quickly, economically and comprehensibly. The photorealistic 3D models enable the identification and analysis of relevant geological features in a virtual environment. 3D measurement data (microstructure, exposure, area measurements, point annotations, etc.) can be managed in a structured way in the database Dibit-TIS (tunnel information system) and statistically evaluated. An export to common BIM and CAD programs is possible.

Furthermore, on the basis of the geometry measurements, profile characteristics of the outbreak, such as over and under profiles are determined. Based on a reference geometry, or on subsequent 3D measurements, it is possible to calculate the volume of shotcrete and other installations. Thus, the geometric-thematic data provide valuable information for the construction and later maintenance of tunnel structures.

After the initial phase at the Perjentunnel the system is now used at different lots of the Brenner Base Tunnel and for the 2nd tube of the Karawankentunnel between Slovenia and Austria.

GEOTECHNICAL SOLUTIONS FOR IMPROVED SEALING AND STABILIZATION OF TUNNELS AND RESERVOIRS

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STABILIZAION WORKS OF TUNNEL WITH STEEL FIBER INSTEAD OF WELDED WIRE MESH AS SHOTCRETE REINFORCEMENT, TRACK DOUBLING PROJECT FOR NORTHEASTERN LINE MAB KABAO – THANON CHIRA JUNCTION CONTRACT C3 – TUNNEL WORKS, THAILAND

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Track Doubling Project for Northeastern Line Mab Kabao – Thanon Chira Junction Contract C3 – Tunnel Works is situated in Saraburi Province and Nakhon Ratchasima Province of Central and Northeastern Thailand. It comprises of three railway tunnels with a total distance of 12.5 km. It is one of the flagship track doubling projects of the State Railways of Thailand of which the contract was awarded to the Joint Venture of ITD – RT as an EPC contractor. The stabilization works of the tunnel during construction period and for its long-term use with utmost safety of the workers and the train passengers is of prior importance. One of those stabilization works is the shotcrete supporting work. The tunnels had been excavated using a drill and blast method through various kinds of rock conditions of sandstone, siltstone and shale. A typical tunnel section is designed for two single track tunnels of approx. 8x9 m (W x H), horse shoe-shaped cross section and one double track tunnel of approx. 12x9m (W x H). According to initial technical specification, the shotcrete support is required with welded wire mesh of 4mm and 150mm square reinforcement fixing to the specified tunnel crown and walls before shotcrete spraying. The compressive strength of the shotcrete at 28 days of 30 MPa is required. To date, the shotcrete spraying onto the fixed welded wire mesh had been carried out for a period of about six (6) months since beginning, using a minimum of eight (8) workers for a time consuming of about 3-4 hours for fixing the welded wire mesh of approx. 200m^2 whereas the total area of the mesh fixing is more than 200,000 m^2. Thus, the Contractor has proposed the steel fiber instead of the welded wire mesh as the shotcrete reinforcement to the Client. Its usage advantage is evidently the savings of the manhour of labor that is due to no fixing of the welded wire mesh. The ready-mixed shotcrete with steel fiber from concrete batching plant can be immediately sprayed to the tunnel surfaces. Meanwhile the initial requirement of steel fiber content of 60 kg per cubic meter of shotcrete was specified in the Technical Specification. However, the Contractor has proposed the deviating quantity of the steel fiber for the works of 25 and 30 kg per cubic meter of shotcrete. Further, the quality control of the shotcrete with steel fiber reinforcement is subject to the European standard of EN-14488-5 testing of which energy absorption of test panels shall not be less than 700 Joule.

OFF-GRID POWER SUPPLY FOR TUNNELING AND MINING EMPLOYING RENEWABLE ENERGIES

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ENERGY SHEET PILINGS - A MILESTONE FOR EMISSION FREE, RENEWABLE POWER PRODUCTION

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