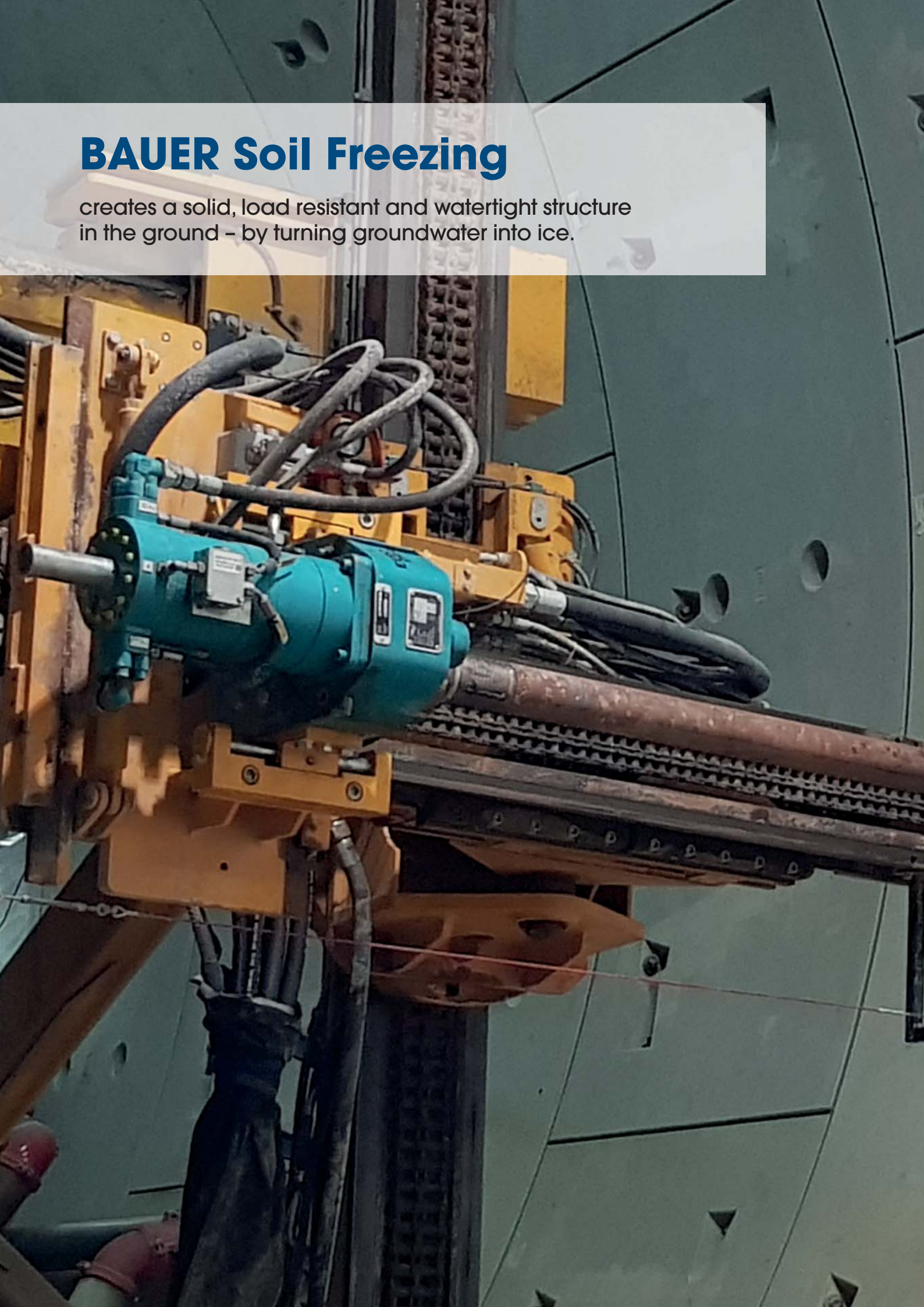
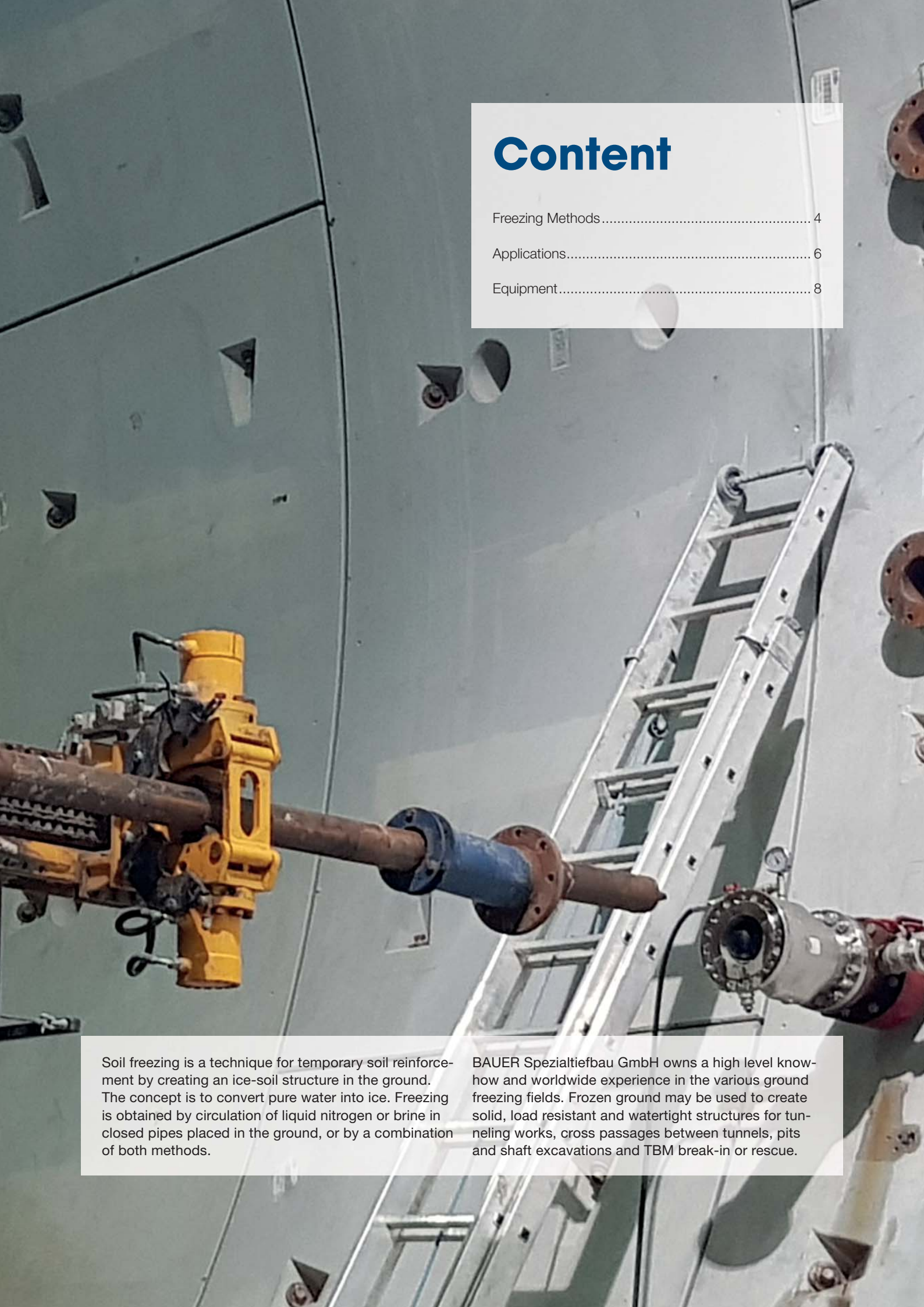
BAUER
Soil Freezing



BAUER Soil Freezing

creates a solid, load resistant and watertight structure
in the ground – by turning groundwater into ice.

Content



Soil freezing is a technique for temporary soil reinforcement by creating an ice-soil structure in the ground. The concept is to convert pure water into ice. Freezing is obtained by circulation of liquid nitrogen or brine in closed pipes placed in the ground, or by a combination of both methods.

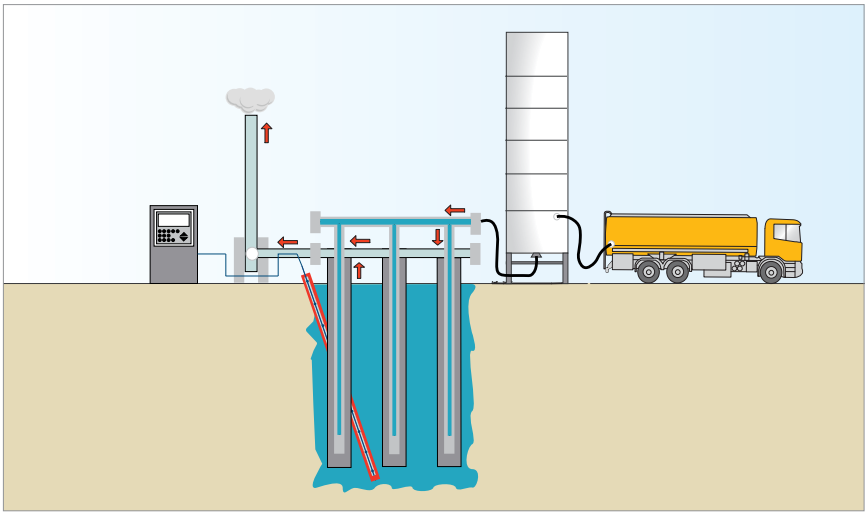
BAUER Spezialtiefbau GmbH owns a high level know-how and worldwide experience in the various ground freezing fields. Frozen ground may be used to create solid, load resistant and watertight structures for tunneling works, cross passages between tunnels, pits and shaft excavations and TBM break-in or rescue.

Freezing Methods

There are two different freezing methods which can be used for soil freezing. The direct method is freezing with liquid nitrogen (IN2). This method takes a short freezing time but it has high energy and maintenance costs. The indirect method is freezing with liquid brine, which offers low energy and maintenance costs. It takes around 20 to 30 days for freezing the ground – but this method is also suitable for confined spaces. The so-called mixed method is a combination of freezing with liquid nitrogen and brine.

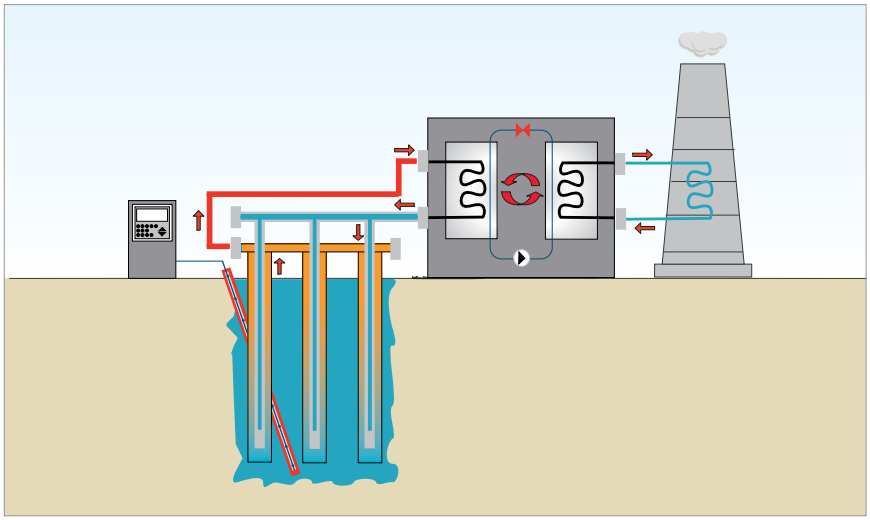
Freezing with liquid nitrogen – the direct method

Nitrogen is maintained in a liquid state in an insulated tank slightly above the atmospheric pressure. At a temperature of -196 °C the fluid circulates in copper pipes installed in the ground and freezes the soil around the pipes. The exhausted gas is released into the atmosphere. Under normal conditions, freezing of a soil body is completed within 5 to 8 days. A system of temperature measuring points allows for monitoring of the freezing process and optimization of nitrogen consumption.



Freezing with brine – the indirect method

Brine is a nearly 30% solution of calcium chloride in water. Brine is circulated into the ground inside low carbon steel pipes forming a closed circuit between the pipes and the freezing plant. It circulates at a temperature of approx. -35 to -38 °C under normal conditions, freezing of a soil body is completed within 20 to 30 days. A system of temperature measuring points allows for monitoring of the freezing process.



Freezing with liquid nitrogen and brine – the mixed method

The so-called mixed method uses the liquid nitrogen for the freezing phase and the brine for the maintenance phase. It saves time for the freezing phase compared to the brine method.

On the other hand it can be quite expensive, since it requires the installation of a separate distribution system for both brine and liquid nitrogen and the use of copper pipes inside the steel freezing pipes.

After the nitrogen freezing phase, the temperature of the copper pipes needs to be above -35 °C for the liquid brine to circulate, otherwise the brine could freeze into the pipes.

Choice of the method

	Freezing phase	Maintenance phase	Work in confined spaces	Soil frozen volume > 1,000 m³	Maintenance / Duration > 2 weeks
Liquid nitrogen	liquid nitrogen	liquid nitrogen	not suitable	expensive	expensive
Brine	brine	brine	suitable	suitable	suitable
Mixed method	liquid nitrogen	brine	not suitable	expensive	suitable

Advantages and disadvantages of the methods

	Brine	Liquid nitrogen
Freezing time	20–30 days	5–7 days
Site installation costs	100–300 €/m³	80–150 €/m³
Freezing energy costs	10–15 €/m³	70–100 €/m³
Maintenance energy costs	0,5–1,0 €/m³/day	7–10 €/m³/day
Use in closed space	very low risk	high risk (in case of gas losses)
Risk with groundwater under movement	risk if v > 1–2 m/day	risk if v > 5–7 m/day
Heave risk	high risk in clay	lower risk, also in clay

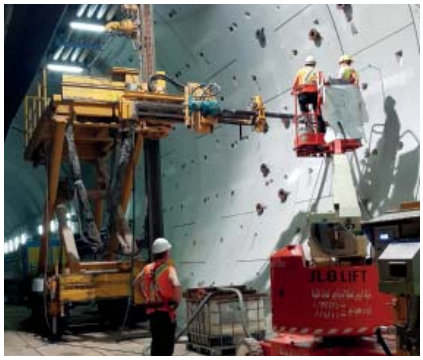
Tunnel Ismailia, excavation of a cross passage

Applications

The soil freezing methods with liquid nitrogen, brine or a combination of both can be used for different scopes, e.g. for cross passages, open pit and shaft excavations. BAUER Spezialtiefbau GmbH additionally used soil freezing for the rescue and break in of a TBM (Tunnel Boring Machine) at two different sites. Soil freezing provides flexible solutions for different kinds of requirements and tasks.

Cross passages

Soil freezing has been used to create a load resistant and watertight cylinder around the zone of excavation of cross passages. The 4.5 km long Ismailia road tunnel crosses the old and the new Suez Canal. The brine freezing method has been chosen to create a cylinder of frozen soil around the four cross passages to be excavated. One special scissor lift drilling rig was constructed for this scope. Up to four 100 kW freezing plants have been employed.

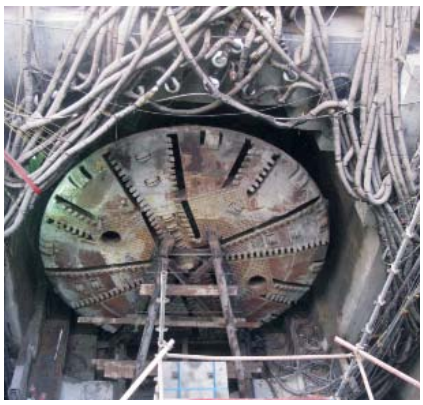


Open pit excavations

Soil freezing was used to create a load resistant and watertight structure around the zone of excavation of an open pit. At the Staatsoper Berlin project soil freezing was realized. Due to the presence of an existing building, one part of the secant pile wall had to be replaced by brine freezing. 18 freezing pipes and three thermometer pipes were drilled and installed from inside the existing building. Due to the long maintenance period of eight months, the brine method had been chosen. The frozen soil wall had been anchored.

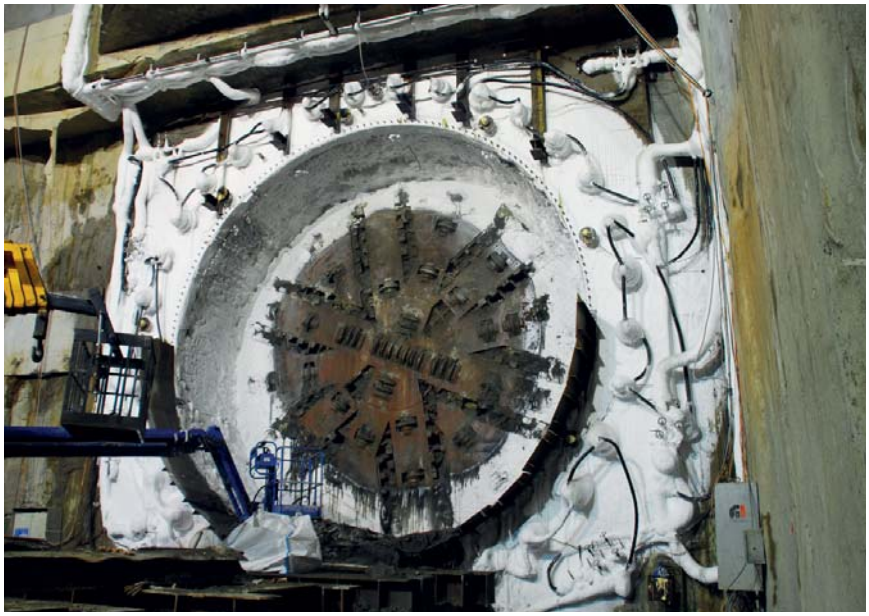
Rescue of Tunnel Boring Machines

Soil freezing with brine was used to create a load resistant and watertight structure around the head of a blocked Tunnel Boring Machine (TBM) at the Cairo Metro line 3. A number of 86 horizontal freezing pipes, 12 horizontal and three vertical thermometer pipes were drilled and installed into fine sands and against water pressure. Two freezing plants with a cooling capacity of 110 kW each were used for this project.

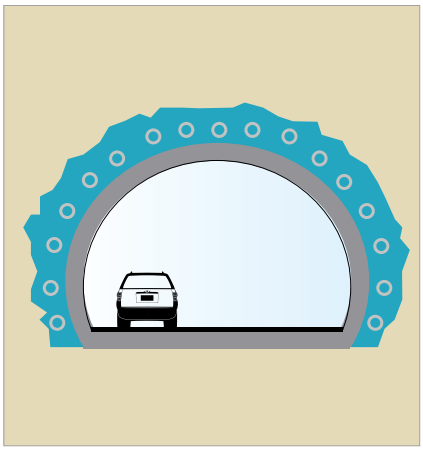


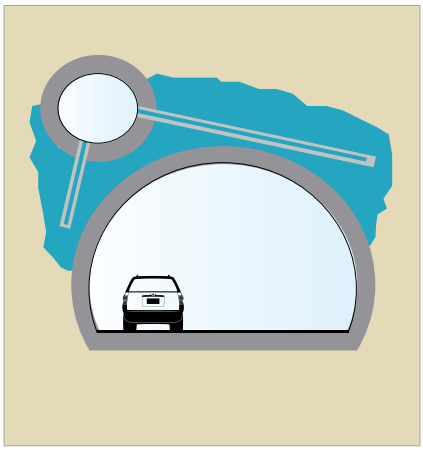
Break-in and Break-outs for Tunnel Boring Machines

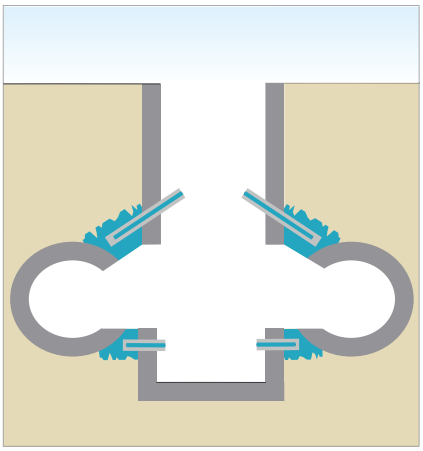
Liquid nitrogen freezing has been used for two TBM break-in rings from the Üsküdar Metro Station in Istanbul, Turkey. A ring of frozen ground by means of liquid nitrogen freezing was realized. 33 horizontal freezing pipes and 12 horizontal thermometer pipes were drilled and installed into fine sands and against water pressure. Two 20 m³ tanks were needed to store the liquid nitrogen and supply it to the freezing pipes.



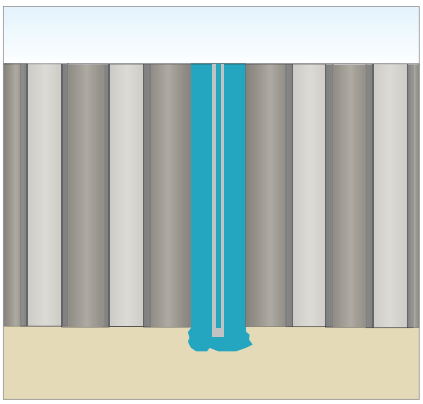
Tunnelling applications



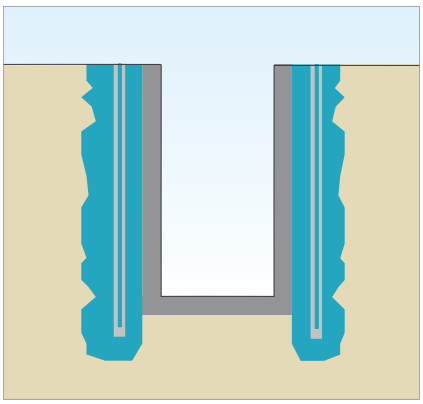




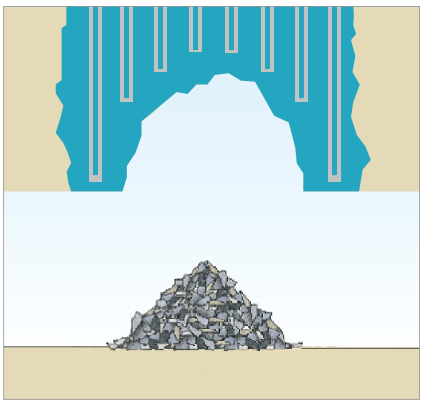
Other applications



Closing of gaps in bored pile walls



Shaft excavations



Redevelopment of collapses

Equipment

Soil freezing can be realised with brine or liquid nitrogen – or a combination of both methods. Typical drilling equipment, like the Klemm KR 806 or KR 704, is used to install the freezing pipes.

Drilling methods

Used for the installation of freezing pipes:

- Rotary drilling with lost freezing pipe
- Rotary drilling
- Rotary drilling with down-the-hole-hammer
- Rotary percussion drilling
- Overburden drilling
- Double head drilling rotary/rotary
- Double head drilling rotary/rotary percussion

Klemm Hydraulic Drill Rig KR 806-3F

For drilling under confined spaces (galleries, shafts) the short mast rigs of the Klemm KR 700-series with diesel or electric motors with separate power pack are the most suitable solution.

Klemm Hydraulic Drill Rig KR 704-1

Special drilling rigs

A special short mast rig, placed on an elevating platform has been designed and constructed for cross passage applications in tunnels.

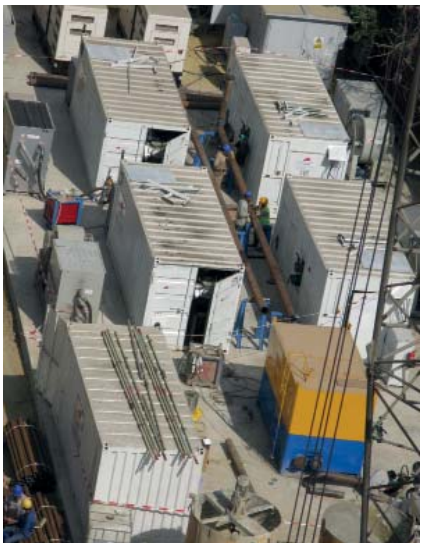
Freezing equipment

Freezing with liquid nitrogen

The liquid nitrogen is stored on site in double-walled storage tanks (under vacuum), where it retains its physical properties until use. The distribution circuit is made of insulated copper pipes and automatic feed valves activated by temperature sensors. The nitrogen gas is collected in an exhaust pipe circuit and finally released into the atmosphere.

Freezing with brine

The brine (a solution of calcium chloride in water) is cooled to a predefined temperature of -35 °C using dedicated freeze units (chillers). The distribution circuit is made of insulated HDPE pipes, valves and temperature sensors. After the circulation in the freezing pipes, the brine returns to the chiller to be cooled again.



Quality Control

Ground freezing requires an increased level of quality assurance and quality control measures. Compliance with the specifications and quality requirements are checked and documented by the QC department. The daily controls of drilling (drilling rate, deviations pipe tightness) and freezing (soil and brine temperatures, pore water presure) are the key points to achieve the project requirements regarding expected quality and schedule.

Measurement of borehole deviation

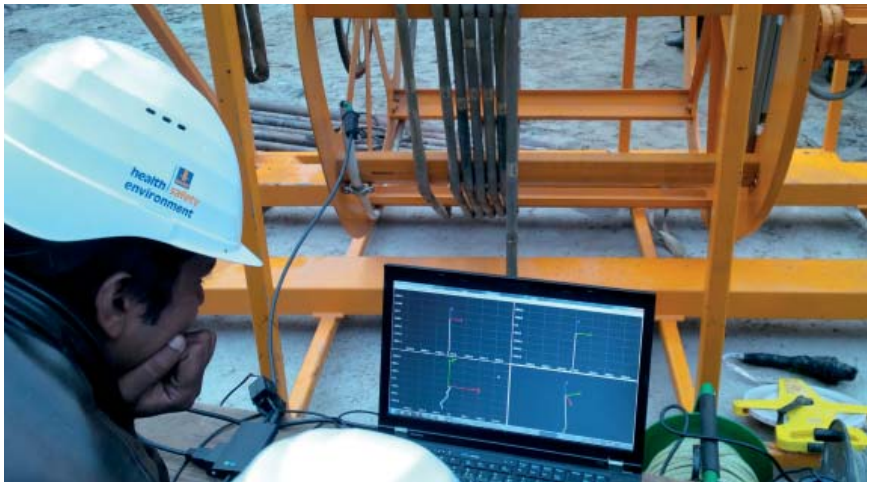
Soil freezing structures are reaching into ever greater depths. Hence, requirements to comply with limited hole deviation are increasing. There are various systems available for controlling and monitoring the deviation of the borehole from the design direction, like the Shape Accel Arrays (SAAF) Gyro, Glötzl or Maxibor. Even if the drilling rig has been precisely set up, every borehole has a tendency to deviate from its intended path into the ground.

The magnitude of borehole deviation depends on a variety of coincident factors:

- soil type
- presence of stones or boulders
- hole geometry
- type of drilling rig
- drilling method
- diameter and material of the drill string

As-built drawings of the freezing pipes are produced in order to verify if additional boreholes may be required.

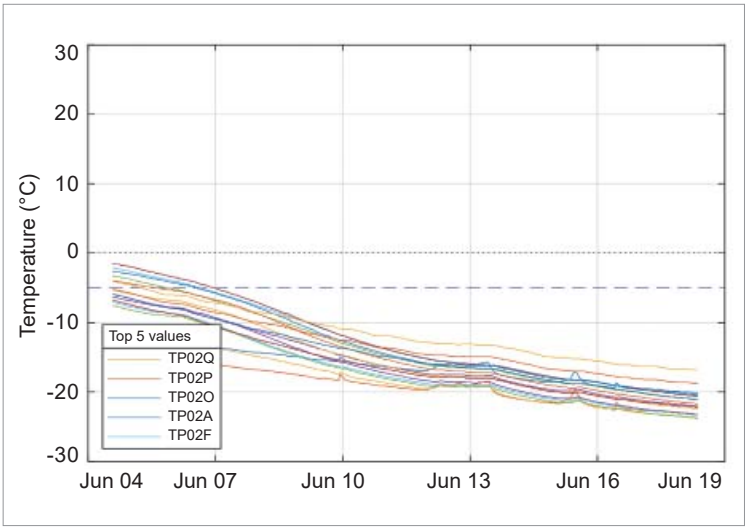
Inclinometer drum



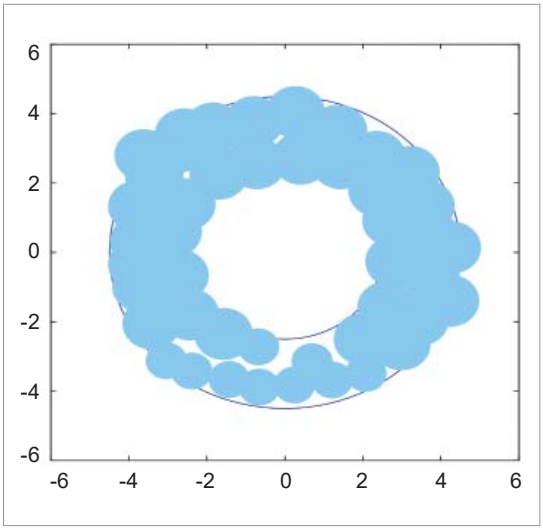
Technical evaluation of the measurement

Temperature measurements

The continuous measurement and monitoring of the soil temperature at several locations within the ice body is fundamental for the evaluation of the development of the frozen structure and the determination of its completeness and homogeneity. Graphical presentations are useful to verify the evolution of the process and to determine its completion.



Example of temperature/time measurement

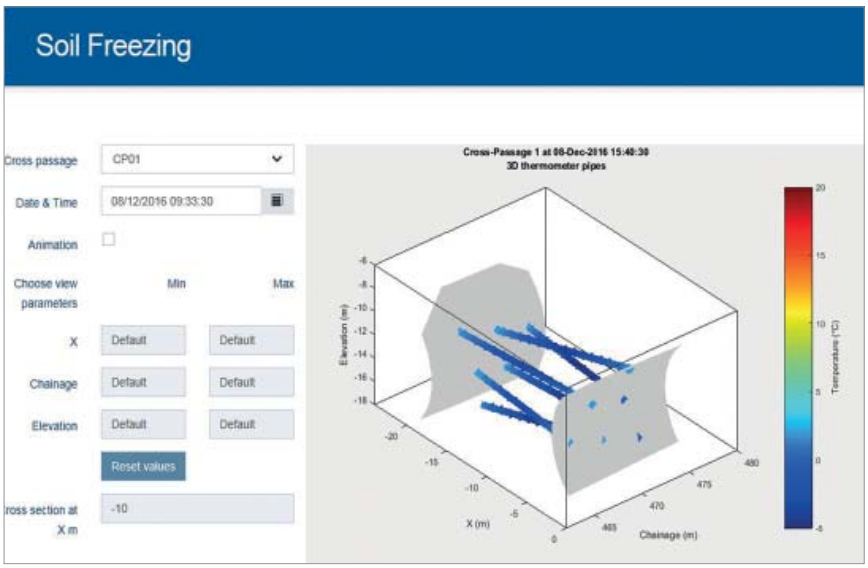


Estimated ice column diameter around the cross passages

QC Documentation

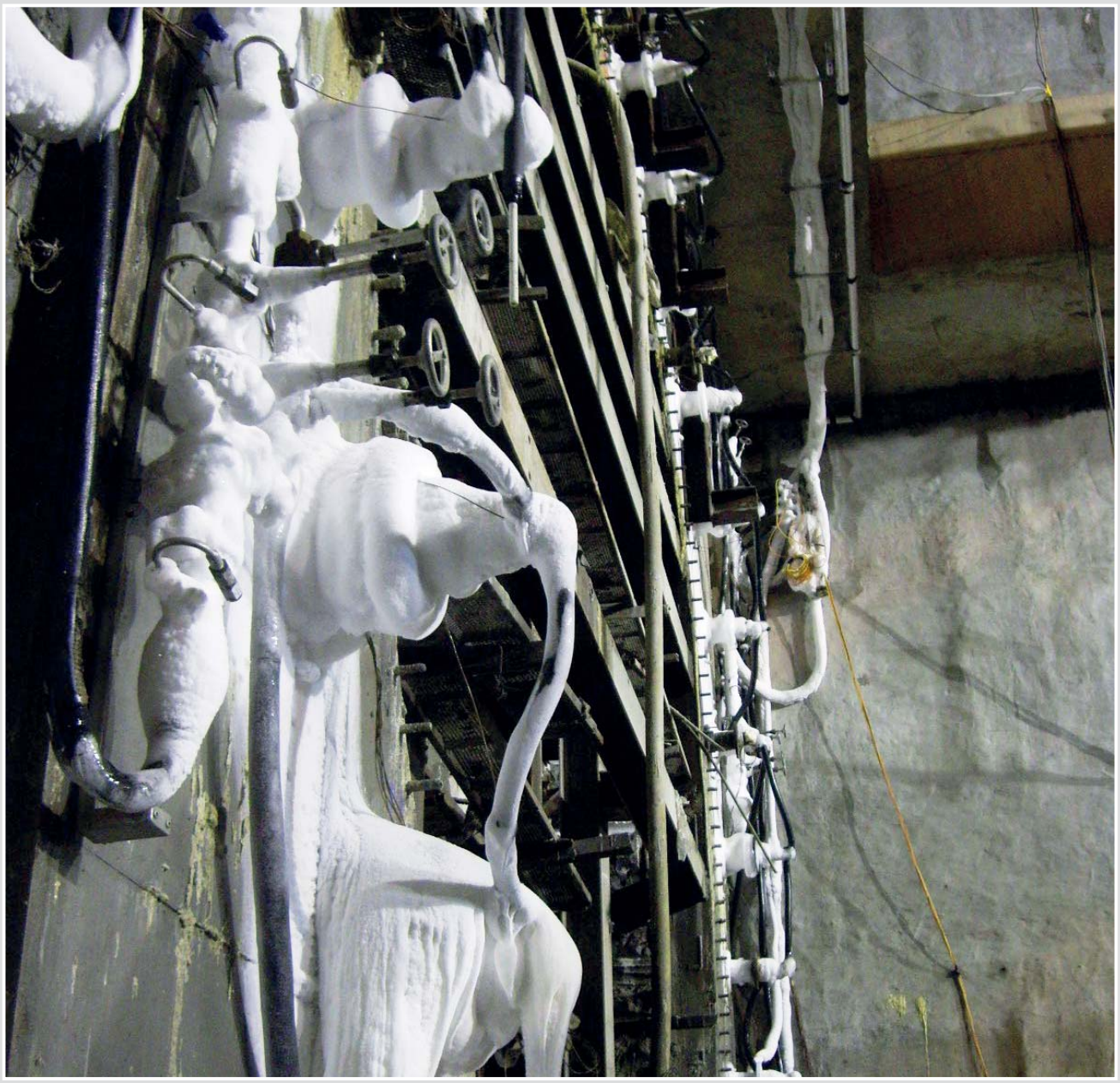
The following list shows in detail which data is recorded and documented during the performance of the drilling and freezing works.

- Daily report: In this report all site resources including personnel and equipment and all daily activities of drilling and freezing performance including material are summarized.
- Drilling report: Includes information on on the drilling fluid, hole position, drilling parameters and layer sequence, type of formation, installation of the freezing and thermometer pipes and execution time.
- Freezing reports: Showing soil temperatures and pore pressure data.



Example of 3D ground temperature visualization for a cross passage

BAUER Spezialtiefbau GmbH
BAUER-Strasse 1
86529 Schrobenhausen, Germany
Tel.: +49 8252 97-0
Fax: +49 8252 97-1496
BST@bauer.de
www.bauer.de



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