Introduction
Ground freezing technology was originally developed for mining. It was used for the first time for mining shafts in the United Kingdom (1862) and Germany (1883).

Ground freezing is a temporary construction support measure that takes advantage of the positive characteristics of the high solidity and impermeability of frozen ground.

Principle of freezing
The basic principle behind ground freezing consists in the forced withdrawal of heat from the soil. In the process, underground pore and fissure water is frozen thereby solidifying the soil and cutting off the movement of water due to the impermeability of ice. Ground freezing can be used in all wet soils and materials. Dry, non-cohesive soils can be prepared for ground freezing by way of the controlled injection of water.

For the purpose of freezing the soil, freeze pipes are inserted into the ground at calculated distances. A freeze pipe contains another pipe at its center, called a drop tube. Coolant is pumped into the drop tube at the top. Then it runs through this centrally positioned tube to the bottom of the freeze pipe. The coolant then flows from the bottom of the freeze pipe back up to the top in the annular space between the drop tube and the outer wall of the freeze pipe. As it flows from the bottom back up to the top of the pipe, heat is extracted from the surrounding soil which causes it to freeze.
Once the soil freezing point has been reached, a frozen body forms expanding radially outward from the freeze pipes. As it grows, the individual frozen bodies surrounding each freeze pipe converge to form a single frozen mass. The thickness of the frozen mass gradually increases as the core temperature continues to fall. Coolant is passed on to further freeze pipes in a closed loop.

In the **freezing phase**, the cooling unit is operated at full capacity only until the frozen mass has fully formed and reached prescribed static thickness.

During the actual construction measures carried out under the protection of the frozen mass, cooling output is reduced to merely compensate for heat absorbed from the surrounding construction site soil and the exposed portion of the frozen mass. During this **maintenance phase**, intermittent operations are often preferred, i.e. the cooling system is only operated periodically at regular intervals.

The **thaw phase** follows completion of construction measures. Ground freezing is completely and permanently shut off and the frozen body slowly thaws due to the surrounding heat.

A frozen mass can generally be constructed in any shape if the required pipes are positioned accordingly.
Applications
Ground freezing has many applications, such as:

**Tunneling**
- Crown freezing
- Full diameter freezing
- Securing sections during tunneling
- Construction of cross-cuts
- Sealing the joints between tubbing segment and diaphragm wall

**Shaft construction**
- Fixing collapsed or filled shaft structures

**Construction pits**
- Repair of leaks in bored pile, sheet pile and slurry walls
- Construction pit enclosures for difficult perimeter conditions
- Underpinnings
- Pit base sealing
- Temporary gap closure for later flow passage
- Connection of existing tunnels
- Temporary extension of enclosure walls

**Special solutions**
- Extraction of uncontaminated soil samples
- Contaminated site remediation
- Pneumatic piercing of railway underpasses
- Rehabilitation of cracks in tunnel construction

1. Full tunnel enclosure freezing, urban rail line, lot U2/1, Vienna
2. Ground freezing for excavation of cross-cuts between two tunnels, Herrentunnel, Lübeck
3. Construction site enclosure via ground freezing, Chemiepark Marl
4. Freeze pipes for diaphragm wall extension, Wehrhahn line, Düsseldorf
Techniques
Construction engineering utilizes two different procedures for ground freezing: nitrogen and brine freezing.

Nitrogen freezing
This process uses liquid nitrogen as a coolant. Nitrogen is neither poisonous nor flammable. In fact, it makes up about 78% of the air we breathe. Cooled to -196°C, liquid nitrogen is transported to the construction site in a specially insulated tanker truck where it is temporarily stored in on-site tanks. High-quality insulated pipes feed the liquid nitrogen down the drop tubes where it converts to gas as a result of coming into contact with the relatively warm freeze pipes. Due to the pressure created by its own expansion, the gaseous nitrogen flows back up and through to other freeze pipes or, alternatively, directly to the exhaust pipe which releases the gas back into the atmosphere at temperatures of approx. -100°C to -60°C. The evaporation process extracts heat from the surrounding soil and freezes it. Nitrogen flows into the freeze pipes due to the pressure created naturally by evaporation in the storage tank. The amount of nitrogen needed to create or maintain the frozen mass is determined by a solenoid valve/temperature sensor loop. Valves are opened or closed depending on the temperature of the nitrogen gas exiting freeze pipes. Each freeze pipe can be operated at a different cooling output level by adjusting exhaust gas temperature settings. Every temperature change and valve adjustment is monitored at a central measurement and control station where it is documented, assessed and changed if necessary.
Advantages of nitrogen freezing

• Fast creation of frozen mass
• Higher frozen mass rigidity than with brine freezing
• Relatively simple site implementation
• Possible groundwater flow of up to 10m/d max.
• Coolant is safe for environment
• Space-saving for construction site implementation

Disadvantages of nitrogen freezing

• Very high costs from media consumption
• Continuous delivery of nitrogen must be ensured
• Danger of frostbite if touched
• In closed areas (tunnels), ventilation is required to prevent suffocation

Brine Freezing

Brine freezing utilizes a saline solution as cooling agent. Frequently, a calcium-chloride solution (CaCl2) with a dissolved solids content of approx. 30% is used. As opposed to nitrogen freezing, this is a closed system in which the solution is circulated in an insulated closed loop and repeatedly re-cooled at a cooling unit. The cooling unit cools the brine to the desired temperature using ammonia (NH3). The system consists of three thermal cycles:

• Cooling water cycle
• Ammonia cycle
• Brine cycle
In the circulation process, the gaseous ammonia is inducted and subjected to high pressure in a compressor. The highly pressurized gas is then transferred to a heat exchanger (condenser) where it once again converts from a gaseous to a liquid state. The heat energy emitted when the substance changes state is then absorbed by the cooling water, which is then cooled back down in a cooling tower. The resulting liquid ammonia is piped to a throttling device (evaporator) and decompressed. During expansion in the brine-ammonia heat exchanger, pressure on the coolant is reduced while the ammonia evaporates and cools the brine in the process. The energy required by the ammonia to evaporate (heat of evaporation) is taken from the brine, which, in turn, is cooled down to approx. -35°C. The condenser inducts the evaporated coolant thus concluding the circulation process.

The cooling unit and cooling tower can also be equipped with a noise barrier if needed.

**Advantages of brine freezing**
- Lower operating costs than nitrogen freezing (primary electricity)
- Easy controlling of energy flow
- Re-usable coolant

**Disadvantages of brine freezing**
- Slower creation of frozen mass
- Lower rigidity of frozen mass
- Complex construction site set up
- High installation and maintenance expenses
- Groundwater flow only up to 2 m/d max
Drilling for ground freezing and temperature measurement

Drilling for ground freezing is normally executed at 0.8-1.5m intervals using small-scale drilling technology. The precision in positioning the drillings is of the utmost importance – any deviation must not generally exceed more than 1.0% of the borehole depth. The bored holes are monitored and measured to ensure technical precision during the construction process. For longer horizontal drillings, horizontal directional drill rigs are used.

Either the casing pipe remains (lost bit) in the ground to be used as the freeze pipe and the drop tube is inserted inside of it following a pressure check, or a freeze pipe is built into the bored hole and the casing pipe is removed with annular injection. After a pressure check of the freeze pipe, it is also fitted with a drop tube and then connected to the circulation loop.

The bored holes for temperature measurement are produced in the same manner as the freeze pipe drillings, but the diameter of the drilling can be decreased as the temperature measurement pipes are smaller in diameter.

Instead of a drop tube, a temperature sensor chain is built into the temperature measurement pipe. It is fitted with temperature sensors at fixed distances. The number of sensors varies according to the bored depth or monitored area. In order to ensure optimal thermal conductivity, the temperature measurement pipe is filled with brine.

It is especially important to have precise knowledge of the current situation by way of the temperature measurement pipes next to the freeze pipes, because the thermocouples monitor the development of the frozen mass.
Measurement technology – quality assurance

The control measurements of the freeze and temperature measurement drillings have already been explained above, as well as the freeze pipe pressure checks which ensure pipes are free of leaks.

The temperature measurement chains help to monitor the expansion and temperature of the frozen mass. The temperature measurement data is continuously transferred via databus cable and stored on a computer within a container. Not only is the brine temperature in the return pipe of every freeze pipe head measured and recorded by the computer, so are brine temperature, brine pressure and brine flow at the cooling unit feed and return pipes in addition to the collective feed and return pipe. The data is presented in tables and diagrams.

Ground freezing planning

When planning ground freezing measures, the following conditions and parameters need to be taken into account, among others:

• Type and structure, i.e. key figures of the soil layers at the site
• Flow speed and direction of ground water
• Temperature of the ground and groundwater at the beginning of the freezing process
• Geometry of the planned frozen mass
• Drilling precision and distance between drillings (i.e. freeze pipes)
• Core temperature and isotherms of the static frozen mass
• Location and temperature of thermal transfer media near the planned freeze, e.g. pipes, canals

Results of the technical calculations for ground freezing:
• Length of the freeze phase
• Energy needs
• Required output of cooling unit

Ground freezing summary
• Nitrogen freezing is well-suited for the quick implementation of smaller construction measures or as a transitional phase before switching to brine freezing.
• Brine freezing has the advantages of lower operating costs and is particularly suited to longer-term and larger-scale ground freezing measures.
• Ground freezing is an environmentally friendly construction measure with minimal effect on groundwaters (no groundwater lowering necessary)
• The process can be used in practically all types of soil
• High level of safety while the frozen mass is intact (thawing takes time)
• Simple and reliable monitoring options (temperature measurement, input pipes, coolant)