Bored piles are one of the most important elements for deep foundations. They are used to transfer concentrated loads into load-bearing soil layers which lie deep beneath the surface. Another application of equal importance is the use of secant bored pile walls to enclose excavation pits. Such walls can also become an integral part of the superstructure above.

The diameter of each individual pile can be up to 300 centimeters, and they can be constructed in all soil types. The borehole is generally supported either by a steel casing or by supporting fluids. In stable ground conditions, piles can be constructed uncased. A variety of different techniques are used to construct bored piles:

- Rotary drilling, the most commonly applied technique, can be employed to construct both fully and partially cased piles as well as displacement piles.

- Alternatively, a hydraulic procedure can be used to press the casing down into the soil in an oscillating movement. In parallel with the pressing action, a rope-operated grab loosens and excavates the soil.

- With the Hochstrasser-Weise procedure, an oscillating torque mass is used instead of the oscillator to sink the casing.

Additional measures such as shaft grouting, base grouting or underreaming can significantly increase the load-bearing capacity of bored piles.
Driven piles

Driven piles are among the oldest types of deep foundation. In the past, they consisted of wood or steel. Today, both prefabricated and cast-in-situ concrete piles are also used in addition to steel piles.

Anchors

Anchors are employed to transfer the forces acting on supporting structures either into the ground behind them or into the subsoil at a lower level. Depending on the duration of use, a distinction is made between temporary and permanent anchors. Similarly, the soil type determines whether rock or soil anchors are used, and the method of construction determines the choice between standard grouted and post-grouted anchors. Standard grouted anchors consist of tension bars which are installed in a drilled hole, grouted and prestressed. The precision injection of a cement suspension creates a pressure-grouted body in the soil. The various types of grouted anchor commonly used include multi-bar anchors, stranded wire anchors and pressure pipe anchors.

A sealing system developed by Bilfinger Spezialtiefbau GmbH allows grouted anchors to be manufactured even where groundwater pressure is high.
Soil nailing

Soil nailing turns naturally occurring soil into an artificial gravity wall. This is achieved with the aid of soil nails, which are anchored in a reinforced shotcrete shell. The principal application for soil pinning is to temporarily or permanently secure slopes and embankments.

Injections

The purpose of injections is to improve and stabilize soils. Cavities such as voids in loose soil or joints in hard rock are opened up using a drilling technique adapted to the particular soil type and filled with solidifying material. Consolidating or sealing effects are achieved.

Consolidating injections are employed when underpinning buildings and as a safety measure when driving tunnels and galleries.

Sealing injections are used to construct base slabs in preparation for watertight excavation pits as well as to seal dams and embankments to prevent the impound water from passing beneath or around them.

Such injections are also employed to seal leaks. Another application is to decrease the permeability of the soil when working under compressed air or to reduce the inflow of water during the construction of caverns or tunnels.

Specifications of injected material depend on soil conditions and the purpose of application. If the soil is so fine-grained that even injection of ultrafine bonding material is no longer effective, a jet grouting procedure is employed.
Jet grouting

The fundamental concept of high-pressure injection involves the disaggregation of the soil or weak rock and mixing it with or replacing it by a cement suspension. The object of this procedure is to consolidate or densify the soil in a manner largely independent of the soil structure.

Applications for high-pressure injection include the underpinning of buildings, horizontal impermeable slabs, vertical impermeable walls as well as soil improvement and stabilization. The following jet grouting techniques are employed:

Using the single fluid system, a high-pressure jet of cement suspension cuts up the soil and mixes it with the suspension. This procedure is suitable primarily for applications at shallow depth and for horizontal high-pressure injections.

With the double fluid system, the cutting jet of cement suspension is surrounded with compressed air. In comparison with the single fluid system, this procedure allows grouted columns of significantly greater diameter to be manufactured at far greater depths.

With the triple fluid system, the soil is cut by a water jet surrounded by compressed air. The cement suspension is injected via a nozzle at lower pressure beneath the cutting jet. This method is particularly suitable for underpinning buildings.

1 University Clinic, Düsseldorf; soil compaction with the aid of high-pressure grouting
2 Machabäerstraße excavation site, Cologne; exposed high-pressure grouted columns
3 Wiebeck-Schule, Bad Langensalza; high-pressure grouting work under restricted headroom
**Diaphragm walls**

Diaphragm walls are concrete walls cast in situ, which can reach down to considerable depths. These 60 to 150 centimeter thick walls are manufactured using a low-noise, low-vibration process. Diaphragm walls are subject to minimal deformation and therefore feature primarily in deep workings in inner-city areas where they are used to enclose excavations. Because of their relatively high resistance to water penetration, they are suitable for serving as the exterior wall of the subsequent structure. In special cases, individual diaphragm wall elements can also be used as deep foundations.

**Cut-off slurry walls**

Cut-off walls are vertical sealing elements with no structural function. They are not reinforced and are generally constructed as single-phase walls. In other words, the supporting fluid remains in the trench as a sealant and slowly solidifies.

Cut-off walls are used to enclose waste pits, fuel depots or other industrial installations which may constitute a risk to the groundwater. In certain cases, it is practical to install PVC sealing membranes.

With the addition of sheet-piles, cut-off walls can also take on a structural role. This is always of practical benefit when only part of the wall is required to withstand soil or water pressure.
Thin slurry walls
Thin slurry walls too can be used as vertical containment elements to cut off the horizontal flow of groundwater. They are constructed by vibrating steel beams into the ground. Applications include the enclosure of waste pits, waterproofing excavation pits and as the watertight core of soil embankments. In combination with jet grouting procedures, thin high-pressure erosion walls can be manufactured to a thickness of up to 30 centimeters.

Retaining walls
When working deep below ground level in inner city areas, it is generally impossible to support the excavation by only sloping the sides. It is therefore necessary to install retaining systems. The function of the retaining wall is to stabilize the excavation pit and support the soil behind the wall. A distinction is drawn between low-deformation elements - bored piles, diaphragm walls, jet-grouted walls or ice walls - and non-low-deformation elements such as sheet and soldier pile walls or soil nailing.

The most commonly used support method is the soldier pile and lagging wall, also known as the Berlin method. This involves steel beams which are installed into pre-drilled holes, driven or vibrated into position. As the pit is excavated, the spaces between the beams are filled with timber or shotcrete, and if structurally required, the beams themselves may be tied back or braced. Sheet pile walls are employed either if the pit is required to be watertight, or if the soil conditions do not allow for the erection of soldier pile and lagging wall.
Bored pile walls can be constructed with single, contiguous or secant piles. The diameter of the piles ranges between 30 and 150 centimeters. The design is dependent on the load, the geology and the groundwater conditions to be encountered.

Small-diameter pile walls using piles up to a maximum of 40 centimeters in diameter are constructed right in front of existing buildings with little space required for construction.

**Ground freezing**

Freezing is a temporary measure employed to assist with the construction of shafts, pits and tunnels in difficult soil conditions. Freezing pipes within which a refrigerating medium circulates are installed into the relevant ground section. The continuous extraction of heat causes a cylindrical frozen body of soil to form around each tube. This freezing or icing increases the stability of the soil and seals off groundwater. It is also possible to artificially add water via trickle pipes in order to create a homogenous body of ice.

**Quality management**

Foundations are of prime importance for the lasting quality of a structure. Their long-term functionality must be safeguarded by reliable quality control in the course of their construction. Such quality control is made more difficult by the fact that geotechnical engineering works of this kind are generally hidden from view. Nevertheless, specially developed testing and measurement procedures allow the quality of the work to be reliably monitored and consistently documented.

The quality management system employed by the Bilfinger Spezialtiefbau GmbH is designed and certified in accordance with ISO 9001. The principal elements of this system are summarized in a separate manual.