FDP

Full Displacement Piles

Method Statement

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1 Definition and construction principle

FDP piles are full displacement bored piles. The hollow stem displacement tool is rotated and drilled into the ground at a controlled rate of penetration to the specified terminal depth. The drill string is subsequently withdrawn from the ground at a constant speed and rotation. During the withdrawal phase, concrete is pumped under constant pressure through the hollow stem of the drill string to fill the void formed in the ground.

As soon as the drill string has been completely withdrawn from the bore, a reinforcement cage can be inserted into the fresh concrete and driven to the specified design depth.

Following the development of rotary drives with high torque capacities and drilling rigs with extended masts as well as high crowd and extraction forces, the range of diameters and depths for FDP piles has increased significantly and it is possible to install FDP piles in a wide variety of soils, including clays, silts, peat, sands and sandy gravels. By utilising the high crowd pressures generated by Bauer drilling rigs in connection with newly developed automatic control and monitoring systems, it is now also possible to install FDP piles in stiff soil formations and even socket them into weathered rock.

The method is suitable for displaceable soils:

- Undrained shear strength c_u > 15 kN/m²
- SPT < 30 or CPT < 15 MPa (for granular soils)
- SPT < 15 or CPT < 1-2 MPa (for cohesive soils)

The most significant advantages of the FDP drilling technique are:

- Increase in shaft friction and point resistance due to displacement of the surrounding soil
- Low overconsumption of concrete
- High daily production outputs
- High construction quality as a result of Bauer's B-Tronic drilling and extraction assistant providing automatic crowd and extraction control
- Virtually vibration-free drilling process
- Minimal amounts of drill spoil (particularly advantageous in contaminated soils)

2 Construction procedure

The construction sequence for the installation of FDP piles comprises the following key steps:

- Site preparation and setting up drilling rig over pile position

- Drilling the displacement drill string to the specified terminal depth
- Concreting the pile as the drill string is withdrawn from the ground
- Inserting reinforcement cage into the fresh concrete to specified design depth

2.1 Site preparation and setting up drilling rig over pile position

For execution of the piling works, a dry, stable and level working platform must be prepared in the area around the pile position capable of supporting the loads and ground pressures imposed by the drilling rig. The inclination of the working platform should not exceed 3%.

The drilling rig is positioned over the previously set out and marked pile position so that the tip of the FDP drill string is lined up precisely over the pile position. The mast of the drilling rig is vertically aligned using the automatic verticality control system built into the base machine.

The bottom end of the hollow stem is sealed by an ejectable cap or endplate against ingress of water and soil during drilling.

2.2 Drilling and concreting the pile

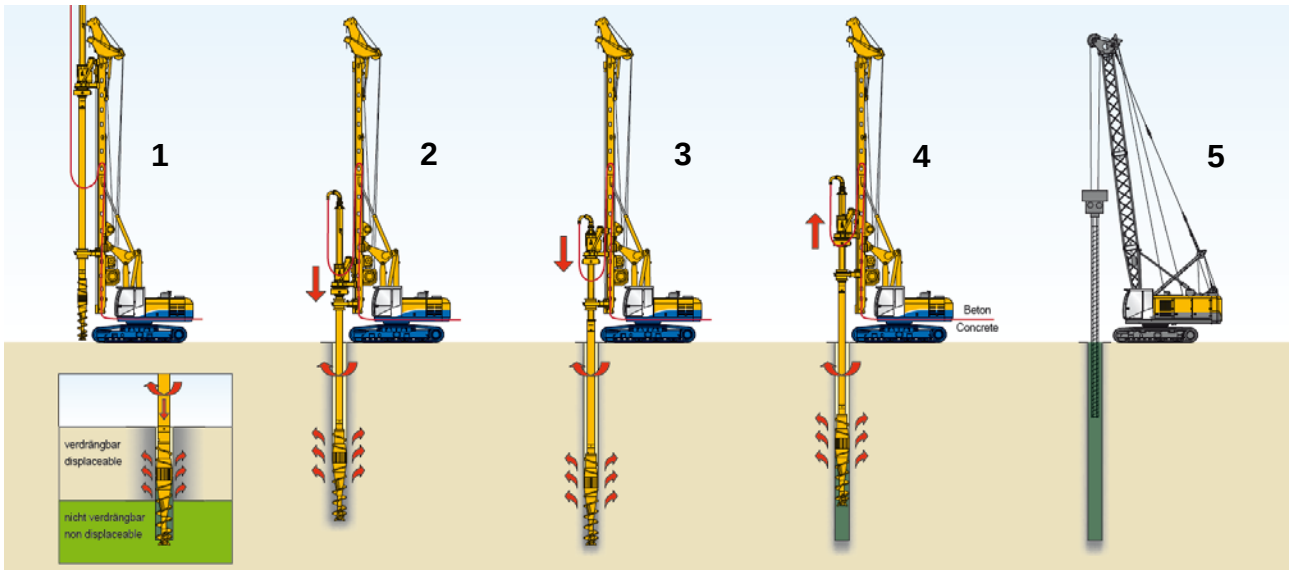
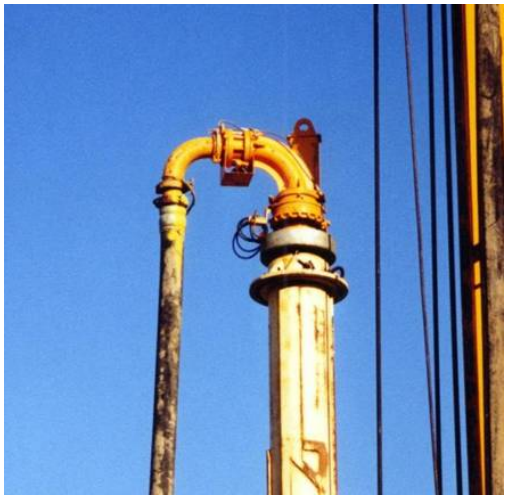


Figure 1: Construction sequence for FDP full displacement piling process

Once the drilling rig is set up over the pile position, the drill string is drilled into the ground to the required depth, extended by optional Kelly extension (**3**), by the torque generated by the rotary drive of the drilling rig and the crowd pressure generated by the crowd winch (**1 & 2**).

If the drilling rig is equipped with a "Drilling Assistant" module, the speed of rotation and the crowd pressure will be automatically regulated and controlled by the integrated computer relative to the rate of penetration after the geometric data of the FDP tool have been input when prompted by the computer.

Upon reaching the required depth (**4**), concrete is pumped into the hollow stem of the FDP drill string via the concrete pipe, swan neck and swivel. A pressure sensor integrated into the swan neck measures concrete pressure. Another sensor registers the strokes of the concrete pump. The previously calibrated concrete volume per stroke is input into the B-Tronic as a parameter. It determines the volume of concrete pumped. Both concrete pressure and volume pumped are displayed continuously on the screen of the B-Tronic. As soon as the hollow stem is completely filled with concrete, the process of withdrawing or extracting the auger at a steady rate begins. The rate of withdrawal is controlled and regulated by an electronic “Extraction Assistant”. The control criteria are the rate of concrete flow and possibly also the concrete pressure.



During the concreting and extraction phase the FDP tool is rotated in the same direction as in the drilling phase. The reverse flights mounted on the upper end of the FDP tool will compact any soil that may have collapsed during the drilling phase into the walls of the borehole.

Figure 2: Swan neck and pressure sensor

2.3 Installation of Reinforcement Cage

In contrast to other bored piling techniques, the reinforcement cage for the standard FDP full displacement pile is installed immediately after the pile bore has been filled with concrete (**5**). Depending on the structural design of the pile, reinforcement can be provided over only part of its length or over its full length.

To ensure that the reinforcement cage can be inserted easily into the fresh concrete, particularly at depth, it is imperative for reinforcement cages to meet the following requirements:

- Reinforcement cages must be designed and constructed as rigid pile cages.
- The concrete mix design must ensure that the concrete remains sufficiently fluid throughout the period required for the installation of the reinforcement cage, particularly where long reinforcement cages are used or where several cage sections are installed which are sliced together by way of overlaps.
- Reinforcement cages must always be installed immediately after concreting has been completed.

Reinforcement cages will normally penetrate into the concrete under their own weight or, if necessary, with some light manual assistance to depths of around 6 to 10 m. For greater

penetration depths reinforcement cages must be installed with the help of a small top vibrator with bar end protection sleeve or pushed/tapped to their specified depths using an excavator bucket.

3 Drilling Rig and Drilling Equipment

3.1 Rotary Drilling Rig

All Bauer BG rotary drilling rigs equipped with a crowd winch system can be readily converted to the FDP piling technique. They are always fitted with FDP crowd systems capable of generating high pull forces.

The achievable drilling depth is determined by the available stroke of the rotary drive. On some rigs both Kelly and lattice mast extensions are available to increase the stroke and therefore the depth capability of the drilling rig.

For optimization of the extraction forces different winch combinations are available depending on the type of rig.

Figure 3: BG with FDP front-end equipment as well as kelly and lattice mast extensions

3.2 Tools

Standard FDP drilling tools are available in diameters ranging from 360 mm to 620 mm. The actual displacement tool at the bottom of the drill string can comprise either a single unit or three detachable sections, as illustrated in Figure 4. This enables the drilling tool to be ideally adapted to the prevailing ground conditions.

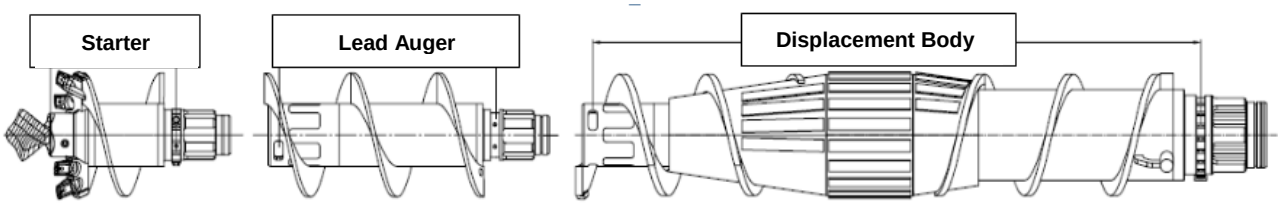


Figure 4: Detachable multi-section displacement drilling tool

The illustrated displacement drilling tool comprises starter auger section, auger lead section and displacement body. In this version the length of the auger lead section is variable. This enables the depth of penetration in non-displaceable soil formations to be increased. The starter auger section can be fitted with round shank chisels or flat teeth.

4 Construction Materials

4.1 Reinforcement Cage

All steel used to fabricate reinforcement cages must comply with the specifications set out in the contract documents, as well as currently applicable standards. Reinforcement cages must be designed and constructed as rigid pile cages to avoid buckling during installation into the fresh concrete of the pile bore.

Reinforcement cages must be fitted with suitable spacers in order to ensure compliance with the specified minimum concrete cover. The bottom section of the reinforcement cage should be tapered inwards to ensure that the cage remains centred during insertion into the pile bore.

4.2 Concrete

All concrete and its components used in the construction of FDP piles must comply with the specifications set out in the contract documents, as well as currently applicable standards.

The maximum aggregate size should not exceed 16 – 20 mm. For the construction of FDP piles it is, however, essential that the concrete mix is sufficiently fluid to facilitate insertion of the reinforcement cages. This requirement is particularly critical for long piles and when piles are to be constructed in permeable soils, which could be liable to water loss and premature stiffening of the concrete.

For reasons of workability of the concrete and its self-compacting properties, the following criteria should be complied with, even if this results in values that exceed the requirements of the project specifications:

- Cement content (dry installation) > 325 kg/m^3
- Cement content (installation under water) > 375 kg/m^3
- Water/cement ratio < 0.6
- Slump flow (consistency classification F 5) 560 – 620 mm (slump 160 – 180 mm)

Prior to commencing any piling works, trial mixes are to be prepared to determine suitable mix proportions, workability and compressive strength of the concrete.

5 Quality Control and Quality Assurance

5.1 Electronic Control System

Putting a reliable measuring and data acquisition system into operation throughout the entire pile construction process is a fundamental requirement.

All Bauer rotary drilling rigs are equipped with automatic verticality control systems which ensure that both the mast and the drilling tools are vertically aligned at all times, thereby assisting the rig operator in drilling properly aligned holes.

Figure 5: B-Tronic screen – left: 'Drilling Assistant' - right: 'Extraction Assistant'

The Bauer B-Tronic electronic monitoring, control and recording system acquires all process-specific production data throughout the pile construction works. These can be visualized for quality control purposes and printed out in the form of a pile record sheet for quality assurance purposes. Use of the Bauer "Drilling and Extraction Assistants" does, in addition, guarantee high and consistent levels of pile quality.

5.2 Soil-specific α-value

Throughout the drilling process the rate of penetration, torque and crowd pressure are measured. Using these data the computer determines the soil-specific penetration resistance (α-value).

This empirical dimensionless coefficient is used as an indication of the density or consistency of the prevailing soil formation. This characteristic soil-specific value has to be gauged on the basis of the soil report. It enables individual pile lengths to be adjusted in accordance with the naturally occurring contour of the load-bearing horizon.

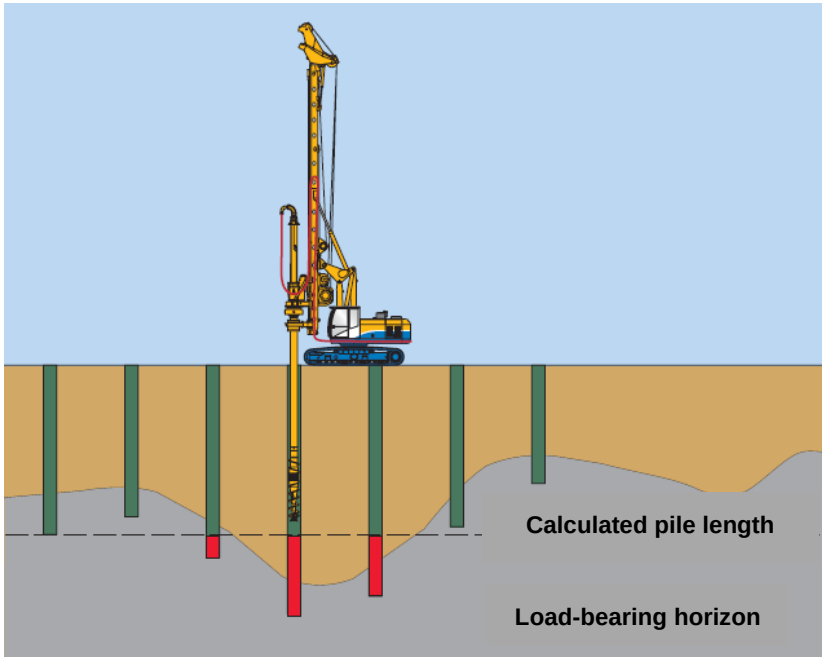


Figure 6: Self-exploratory system for flexible pile lengths corresponding with prevailing geological conditions

6 Safety Measures

For the prevention of dangerous situations or injuries during the piling works the following safety measures must be put in place:

- All site areas to which the public has no access must, for the duration of the site operations, be properly secured by appropriate site fencing which is clearly marked with highly visible warning and danger signs.
- On rest days and during site stoppages all open pile bores must be covered up or secured by appropriate fencing with a height of at least 1.5 m.
- During site stoppages all work tools and machines must be kept in safe storage and locked securely.
- During night work adequate working platforms and lighting must be provided.
- When carrying out maintenance work on machines and drilling equipment the manufacturer’s instructions must be strictly complied with.

- All personnel employed on site must wear suitable work gear including protective clothing such as safety helmets, solid shoes or boots, safety harnesses etc.
- All other safety precautions specified in the General Conditions of Contract must be complied with.

7 Annexes

7.1 List of Equipment

The following list of equipment provides a summary of machines and equipment required for the construction of FDP piles:

Numbers	Description
1	Bauer BG heavy-duty rotary drilling rig c/w FDP front-end equipment
1	Concrete pump with a capacity ranging from 60 to 120 m^3/hour
1	Top vibrator for installation of steel reinforcement cages
1	Backhoe excavator for removal of spoil material and for pushing/tapping reinforcement cages into fresh concrete
1	Optional: Assistant crane for handling reinforcement cages

7.2 Site Personnel

The following table summarizing site personnel required is based on working one shift per day at peak output:

Drilling Operation:	**Number**
Drilling foreman / engineer	1
Rig operator	1
Skilled operative / frontman	1
Reinforcement and concreting:	
Pump operator	1
Backhoe excavator operator	1

8 Disclaimer

The purpose of this Method Statement is to generally describe the Full Displacement Piling Method and the sequence of activities required to execute the method. It describes also the main equipment which will be needed to execute the work.

We emphasize that this Method Statement is a description of events given at the planning stage. Varying soil conditions or differing site conditions may result in a modification of the construction methodology. All data used are either data gathered from various documents or verbal information provided by the customer or assumed by Bauer to be able to complete the MS.

The MS is provided to the customer free of any consideration and as a guide only.

The customer shall check all the data used and recommendations made and come to their own conclusion as to adopt the system proposed or use other or improved methods.

Under no circumstances shall Bauer or the persons preparing this MS accept any type of liability to the same unless agreed through written contract.