Small diameter bored injection piles

by DIPL. ING. H. - W. KORECK*

Introduction

THIS ARTICLE deals with the construction, carrying capacity and applications of a special type of small diameter bored pile. In practice these are known under such names as root-piles, needle-piles, pali radice, as micro piles or as mini piles. In Germany they are referred to as small diameter bored injection piles which, although a somewhat lengthy title, is nevertheless a truly accurate one.

The diameter of the conventional type of bored pile is generally over 300mm while in the case of the small diameter bored pile it is less than 300mm and is normally between 120 and 250mm. But the carrying capacity of the small diameter pile is comparatively very high. A 250mm dia. pile can carry a load of 1,0MN or more; this may be compared with the conventional type, the allowable load (according to the German Code of Practice for Bored Piles) for a 40cm diameter pile being only 0.30-0.37MN.

Main reason for the high carrying capacity is the special method of construction during which concrete or mortar is forced into the soil. But even without specific injection, i.e. with only hydrostatic pressure, they still offer a high carrying capacity which might result from the short construction time and small relaxation of the soil around the drilled hole.

This type of pile can be constructed in all types of soil or rock and they can be drilled in virtually any direction. The pile bases are not enlarged so the load is transferred into the soil mainly through skin friction. The pile is applicable to axial loads in both directions so it can cater for compressive as well as tensile forces.

However only small bending moments can be accommodated and the special method of construction makes the pile somewhat expensive and therefore suitable only in particular situations.

Since the early 50s, first in Italy by Fondecalle and later on in other European countries, small diameter piles were used where buildings needed restoration and foundations strengthening. Since 1965 these piles have been used increasingly in Germany, a development that went hand in hand with the boom in underground construction for roads, subways etc. in German cities.

Equipment and installation techniques

Virtually any type of equipment and drilling method that ensures a stable hole can be used for the drilling operation. This can be carried out with rotary core drill machines which are used for sub-soil investigations or with rotary continuous flush drilling rigs such as are employed in the construction of ground anchors. Casings may or may not be used in both instances. With these machines there are no problems in drilling through existing brick or reinforced concrete walls and foundations; even steel plates present no difficulty, although drill bit wear can prove excessive. A usual pile length is approximately 10m but there are no problems in constructing piles to a length of over 30m —it has already been done.

Conventional drilling machines have undergone development towards lower height clearance and more robust machines (Fig. 1). Restricted height machines are required when working inside buildings with a low headroom. After they have been set-up, the working height of these machines is not more than 2m. They can even be brought into the working site through normal basement doors.

The rigs are powered by electric or hydraulic motors. Very often the drilling mast and the power swivel are located inside the room. The mast extends between floor and ceiling and the rotary power swivel operates up and down the mast controlled from a small panel set up inside the room (Fig. 2). Because of the restricted height in the rooms, only short lengths of drill pipe, of about 1m, can be employed. These require connecting, entailing frequent interruptions in the drilling operation. Under these conditions the reinforcement also has to be in short lengths. Connection of this is generally done by welding (Fig. 3).

Pile construction

The cast-in-place reinforced concrete type

Stages in the construction of this type of pile are shown in Fig. 4. After the drill pipe has been connected to the power head, the drilling fluid, normally a bentonite mud, is circulated downwards inside the pipe and then upwards via the annular space, carrying the debris loosened by the special cutting shoe (Fig. 4-1). When drilling through an existing wall or foundation the diameter of the first drill tube is larger than that of the subsequent ones, to provide egress for the drilling mud.

After the hole has been drilled the reinforcement cage is installed within the drill pipe (Fig. 4-2). Using a tremie pipe, concrete starts at the bottom of the hole (Fig. 4-3), the drill mud being simultaneously replaced with the concrete. The drill pipe is withdrawn slowly while at the same time the concrete is forced into the hole and against the soil by the application of air pressure of approximately 5 atmospheres through the top of

*Institut für Grundbau und Bodenmechanik, Technische Universität, München, Germany

Fig. 1. Crawler-mounted drilling equipment for boring small diameter injection piles (photo, Held & Francke, Munich)

Fig. 2. Drilling equipment operating in a basement (photo, Held & Francke)

Fig. 3. Welding a reinforcement cage (photo, Held & Francke)
the pipe (Fig. 4-4). This procedure continues until the whole of the pile is completed (Fig. 4-5). If the soil is soft in its upper layers, concreting in these strata is carried out with a low air pressure or with only hydrostatic pressure to avoid negative skin friction.

The concrete used is very plastic with a water/cement ratio of 0.4 to 0.6. The cement content, of approximately 600kg/m³ of finished concrete, is high compared to mixes for other construction. Maximum diameter of the aggregate is not greater than 7mm.

The anchor type

Shown in Fig. 5 is another method of construction which is used very often in Germany, the anchor type of pile. Drilling is done with a rotary rig with water flush circulation. The crown is cut with the drilling crown and brought up together with the fluid between casing and drill rod (Fig. 5-1). After reaching the necessary depth the drilling fluid is replaced with cement mortar (Fig. 5-2).

The drilling stem is withdrawn and the so-called pressure pipe (the reinforcement of the pile) is installed (Fig. 5-3). As well as the pipe a reinforcement cage can also be installed. The casing is then pulled out and the cement mortar is injected from the top with a pressure of 15-20 atmospheres (Fig. 5-4). This procedure ensures good contact between soil and finished pile (Fig. 5-5); multiple injections may be carried out.

For this anchor type of construction the maximum sand size used in the mortar is 3mm. The cement content is twice that of the sand and the water/cement ratio is approximately 0.5.

The Micropile-Tubfix type

Another special system is illustrated in Fig. 6. Drilling is done with or without casing. The drilling fluid, a bentonite mud, circulates from the inside through the cutting shoe from which it flows, together with the cuttings, upwards outside the drilling pipe (Fig. 6-1). The drilling procedure is similar to that described earlier.

After drilling is complete the drilling fluid is replaced with a clay-cement or pure cement suspension and the drilling pipe is withdrawn (Fig. 6-2). The reinforcement/injection pipe with valves is then installed (Fig. 6-3). Cement suspension is injected at high pressure through pipe and valves via a plug (Fig. 6-4) until the pile is completed (Fig. 6-5).

When the soil surrounding the hole consists of sand and gravel, the cement suspension also passes into the adjoining ground. If desired a second or third round of injections can be applied. A second phase of injection helps to increase the carrying capacity of the pile in loose sand or in cohesive soils and the procedure is responsible for increased values of skin friction.

Mini-core pile

Another type of pile, a mini core pile or the so-called Gewi pile, is shown in Fig. 7. The core comprises a 50mm steel bar assembly incorporating a system of valves and pipes. The drilling is carried out with casing as in the circulating fluid method; in this case the drilling fluid is water.

After completion of the hole it is filled with cement mortar which prevents buckling and corrosion. The steel bar is then installed. A special external thread on the steel bar enables short lengths to be screwed together after which the casing
Carrying capacity

For piles of conventional type, the controlling factor is generally the external or subsoil mechanics carrying capacity. This is not the case for small-diameter bored piles. Here because the cross-sectional area is very small, the criterion is the internal carrying capacity, i.e., the carrying capacity of the reinforced concrete pile or the bonded construction. Calculation of this internal carrying capacity is made in accordance with existing Codes of Practice.

Piles of a diameter between 16 and 30 cm have to be designed like other reinforced construction. However, smaller diameter piles have a higher reinforcement at joints than is actually necessary and, as a result this over-reinforcement needs particular investigation.

For example, according to the German Code of Practice for Reinforced Concrete, a concrete pile of 15 cm dia. and a reinforcement of eight steel bars of 16 mm dia. can carry an allowable load of 0.46 MN (4.6 kN), the steel bar force being 0.30 MN. When the pile is 25 cm in diameter and contains eight steel bars of 22 mm dia., the allowable load increases to 1.02 MN compressive and 0.73 MN tensile force.

Core piles which have a single massive steel bar of 50 mm, as in the case of Gewi pile, have an allowable load of 0.47 MN. This is based on the area of steel bar, while the cement mortar around the steel is not taken into consideration. The allowable load of both—the core and the mortar—could be increased up to 0.60 MN for a pile of 125 mm dia. In this case the bond strength between steel and mortar requires separate checking in a laboratory test.

Piles with a pipe core of 48.3 mm dia. and a wall thickness of 5 mm have an allowable compressive load of 0.14 MN. The load can be increased up to 1.11 MN for a steel pipe of 114.3 mm dia. and a wall thickness of 17.5 mm. The mortar surrounding the core is not taken into consideration in this case.

It is interesting to note that the calculation is carried for the steel-core types under their maximum allowable loads for compressive force is approximately twice that of the reinforced concrete types.

It needs to be emphasised here that the core of small-diameter pile and structure must be strong enough to transmit the carrying capacity of the pile. Calculation for buckling of the pile is necessary whenever the pile penetrates into a very muddy layer or when it is standing freely, for example in water, or when the steel core is surrounded with a bentonite slurry.

Corrosion is another factor which is important in the case of tension piles. Corrosion can, of course, be prevented by using a special steel or by the treatment of the steel, such as encasing it with plastics.

The external or soil mechanics load-carrying capacity is governed by skin friction, as piles of diameters smaller than 30 cm transfer their loads mainly by skin friction. For example, a pile 20 cm in diameter and 5 m in length has an area of shaft 100 times greater than the cross-sectional area of the pile. Therefore for this type of pile the base resistance is negligible and is not taken into consideration.

So that the internal load-carrying capacity is fully utilised the bearing strata in non-cohesive soil should have a medium density (a relative density of, say, 0.3).

Cohesive soils should have at least a stiff consistency (i.e., a natural water content at or near the plastic limit). For safety reasons the length of a pile should be not less than 3 m in these types of soils and not less than 1 m in rock.

The settlement of small-diameter injection piles is small because the ultimate skin friction is reached at a settlement of between 5 and 20 mm—generally it is attained at a pile head settlement of 10 mm. Furthermore there is the possibility of reducing this movement by prestressing of the pile as this can be done easily with special hydraulic jacks.

The best way to estimate the allowable load of a pile is to carry out a field test. This is easily undertaken because the load required is small and relatively little time is needed. In general the load does not have to be more than 1.5 MN and, depending on the soil, the time required is between 1 to 2 days.

Three typical load test results of piles of different construction and in different types of soils are shown in Fig. 9 a, b, c. It would be relevant here to draw a comparison (of skin friction) between conventional bored piles and small diameter piles. In a non-cohesive soil of medium density the value of ultimate skin friction for an injected small diameter pile is about 0.30 MN/m². This value increases to about 0.45 MN/m² when a second phase of injection is applied. Even without injection, i.e., a pile constructed under hydrostatic pressure only, an ultimate skin friction of about 0.15 MN/m² can be achieved in a loose to medium dense sand. Compared with these values the ultimate skin friction in the case of conventional types of bored piles is of the order of only 0.05-0.10 MN/m².

Load tests carried out by various contractors with some building agencies have provided useful data for estimating the load design of small diameter bored piles. Tests on ground anchors, which are in principal performed in a similar way to the piles, provided additional data on the values of skin friction (see Jelinek and Ostermayer, 1976). Their tests on anchors of a diameter smaller than 13 cm revealed that the skin friction decreases with an increase in diameter. In general injection bored piles have diameters larger than 13 cm. For the piles the anchor values published should be used with care. Another reason for a careful application of test results is the fact that test piles or test anchors are always constructed under controlled conditions, which is not possible during a normal daily routine. Data from these tests should therefore be taken as maximum values.

For the design load it needs to be borne in mind that these piles have little or no carrying capacity in reserve in base resistance compared to bored piles of large diameters. Thus failure occurs abruptly and after even small movement.

In thick layers of soft soil where nega-
dations, for the protection of buildings next to deep excavations, and they can supersede classical underpinning.

In many countries during recent years ancient and historical buildings that had settled unevenly and showed cracks have been repaired and preserved by using these piles. The schematic drawing, Fig. 10, indicates how the piles can be arranged. The holes are drilled at an inclination through the existing walls or foundations (Fig. 10a). They also can be drilled vertically and fixed to special concrete beams along side the existing walls which are spanned together (Fig. 10b). In addition to the remedial work for foundations, the piles will at the same time knit together dilapidated or bad construction. In certain cases the piles also serve as reinforcement (Fig. 10c).

An example of a preservation job is the work done for four eight-storey apartment houses in the German town of Weinheim. The houses had tilted more than 20cm to one side when settlement observations began in August 1969. Fig. 11 shows a part of the grillage foundation and the arrangement of the piles under one of these houses. A decision on the required pile length was made after loading tests were made on piles of different lengths (Fig. 9a). The inhabitants of these houses did not have to leave their apart-

![Fig. 10. General arrangement of the use of injection piles for restoration work](image)

![Fig. 9. Three typical load test results: (a) Load test result of a cast in place reinforced concrete type of pile, carried out by Held & Francke and the Technical University, Munich. (b) Load test result of an anchor type pile with a second injection, carried out by Stump and Degebo Berlin. (c) Load test result of a cast in place reinforced concrete type of pile, carried out by Riepl and Landesgewerbeanstalt Nürnberg](image)
ments while the remedial works were being carried out. After the piling scheme was finished the settlement stopped immediately as shown in Fig. 11.

Another application of small diameter bored injection piles is that of a four-storey building in Naples on top of which five additional storeys had to be built. The new columns were founded on small diameter bored piles which were constructed from inside the building (Fig. 12).

To reduce pollution a new law in Germany required that factory chimneys had to be of a certain height. In many cases it was not necessary to build completely new chimneys; it proved possible to raise existing ones and to strengthen the foundations with small diameter bored injection piles. This system proved most suitable because of its ability to take up compressive as well as tensile forces.

Another application of small diameter injection bored piles is in connection with the protection of buildings sited next to deep excavations. Instead of underpinning, injection piles can transfer the load into deeper layers. The additional amount of settlement is small. Sometimes in non-cohesive ground a grout has to be injected into the soil to bind together stones and gravel.

Often ground anchors need to be installed to carry the horizontal loads; they are absolutely essential for deep excavations. Ground anchors are also necessary for shallow excavations where the piles are drilled with an angle of inclination from the outside of the building. A schematic drawing is shown in Fig. 13.

Fig. 14 shows some anchored piles below the foundation of an eight-storey building in central Munich, where an underpinning job was done with small diameter bored injection piles; it should be noted that the second pile was damaged by excavation equipment.

Fig. 15 shows another underpinning project, where a cement plant had to be enlarged. A new single footing had to be installed exactly below an existing one. Again, this work was done with the help of small bored injection piles; Fig. 16 shows the excavated area with free-standing piles under the footing.
Today underground construction in cities all over the world presents similar problems. Very often a tunnel has to be constructed beside or below an existing building and very often the distance between the two is not more than a few metres. With the aid of small diameter bored injection piles such problems were solved in Milan, Munich, Hannover, Berlin, and other cities. In Hamburg for example, the underground railway track had to be built beneath one edge of a block of flats. Fig. 17a shows the ground plan of the building. For intermediate support the piles were constructed from the basement through the existing foundation. To support a prestressed reinforced concrete mat under the building a tunnel was dug and from here a wall of piles was constructed. This mat was supported on the other side outside the building by means of a slurry trench wall (Fig. 17b), after which the ground under the foundation was dug out. At that time the building was carried on provisional piles (Fig. 18). After construction of the reinforcement mat (Fig. 19), the underground tunnel was dug out in stages. The piles of the side wall were tied back with ground anchors and the lower ends of the piles under the mat were cut off (Fig. 17c). After excavation was complete, work on the underground construction could begin (Fig. 20).

Conclusions

With technological advances in the construction of drilling machines it has now become possible to utilise small diameter injection piles for various foundation problems. The versatility of its use has been demonstrated with the help of a few examples covering various cities.

The main advantages are that these piles are installed without vibration and noise, pile settlement is small and they can be used to advantage where conventional piles would not serve the purpose. Furthermore, this type of pile is capable of carrying much higher loads than the conventional type of pile and is ideally suited for strengthening existing foundations and protecting buildings next to deep excavations.

References


References from contractors

Fondedile SPA, Naples: "Impresa per l'esecuzione di lavori specializzati".

"Root-pattern pile underpinning". Held & Francke Bau AG, Munich.

Insolnd Ges. m.b.H., Salzburg: Mikropfähle.

"High Capacity Micropiles". Stump Bohr GmbH, Munich.

"Root-pattern pile underpinning". Held & Francke Bau AG, Munich.

Recently the German Pile Committee has started to develop a new code of practice for small diameter bored piles.

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