

# Modern technologies of foundation building in the conditions of weak soils of St. Petersburg

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**Abstract.** When performing zero-cycle works in Saint Petersburg, it is necessary to take into account the properties of soils of surface strata represented by late glacial and post-glacial lake and marine deposits that serve as the Foundation of shallow foundations - they contain most of the body of friction piles in pile foundations. The presence of a large number of different technologies for manufacturing piles often puts developers before a difficult choice, which must take into account many different factors – the design of the construction object, the specific engineering and geological conditions of the construction site and of course the cost of the work performed. For many new technologies, the regulatory and technical framework is still insufficient. Their information provision is also lagging behind. Developers and investors sometimes do not know the advantages and disadvantages of a particular technology for making piles and the limits of their applicability, often stopping at the cheapest offers that do not always ensure the reliability of the future foundation.

## 1 Introduction

Currently, St. Petersburg is one of the leading cities in Russia, where methods for improving the properties of soils, as well as numerous modern technologies for the construction of foundations and, first of all, pile ones, have found application for industrial and civil building.

The prerequisites for this, in many respects, were the complex engineering and geological conditions of the current territory of the city, which underwent numerous glaciers with the formation of seas and glacial lakes during different geological periods.

As a result, relatively strong moraine deposits have formed in the central part of the city, which occur at depths of up to 30 m and higher from the day surface.

## 2 Methods

In the work of the zero cycle in St. Petersburg, it is necessary to take into account the properties of soils of the above sea level stratum, represented by late glacial and postglacial lake and marine sediments. Basically, it is these soils that serve as the basis for shallow foundations - they contain most of the body of friction piles in pile foundations.

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For these soils, when used as bases, the following processes are characteristic:

- a) large, uneven, long-lasting undamped deposition of buildings and structures and the surrounding territory;
- b) loss of stability of the bearing layers of the foundations of buildings and structures, composed of dusty clay soils in a state of incomplete consolidation or subjected to freezing-thawing;
- c) destruction of the natural structure of soils in the traditional methods of excavation;
- d) quicksanding phenomena during open drainage from foundation pits and trenches;
- e) change in the bearing capacity of piles due to the development of negative friction forces in areas raised by reclaimed or bulk soil;
- f) development of the rotting peat processes, organic inclusions in the soil and wooden elements of underground structures while lowering the groundwater level.

Many construction sites in the newly developed areas of the city are characterized by a large thickness of weak water-saturated thixotropic soils, their significant heterogeneity in terms and depth, both in composition and in basic physical-mechanical and strength properties.

The knowledge and accounting of these complex processes largely determines the professionalism and success of the construction organizations involved in the work related to the construction of bases and foundations.

### **3 Results and discussion**

Over the past 25 years, the city has undergone major changes in relation to zero-cycle work. New construction organizations specializing in geotechnical work came to the construction market, modern machines and technologies have appeared and are widely introduced.

A typical example may be that in the city territory compared to 1990, the share of use of driven piles almost halved. They were replaced by more advanced sparing technologies such as indentation of piles, including into leading wells, the widespread use of drilling, bored and injection piles of various lengths and diameters, using the “wall in soil” method and others.

Until the beginning of the 90s, the main type of pile foundations was prefabricated reinforced concrete piles, the use of which turned out to be very dangerous for old buildings during the construction of new structures around them. Numerous accidents and damage to neighboring buildings when driving piles at distances of up to 20, and sometimes more meters, forced designers and builders to seek and widely introduce new technologies that have a more sparing effect on the surrounding buildings.

Partial abandonment of the method of driving, led to the development of technology for static indentation of piles. Leningrad was one of the first training grounds where this technology began to be applied on an industrial scale from the mid-70s. Non-self-propelled installation of the design of the trust No. 101 Glavleningradstroy allowed creating an indentation force created by two hydraulic jacks up to 2000 kN.

Since the beginning of the 80s, the 28th Glavleningradstroy trust (now the 28th Building Trust CJSC) has been used, developed by VNIIGS, NIIOSP named after N.M. Gersevanov and other organizations, self-propelled pile-indentation installation USV 120/180 based on the EO-6122 excavator. It consists of a base machine and a loading trolley and allows for indentation of piles with a face size of 30 to 40 cm from 4 to 16 m long with a maximum force of 850 kN at a distance of 1 m from an existing building. Indentation of piles of the same length can be carried out at a distance of 4.5 m from the building at sections of 30x30 and 35x35 cm with a force of up to 1200 kN, and at sections of 40x40 cm - up to 1800 kN. The productivity of the installation in the ground conditions

of St. Petersburg is from 8 to 2 composite piles per shift, respectively, from 16 to 28 m long.

The upgraded USV-120M installation, which has been successfully used in St. Petersburg for more than 10 years, has an increased own weight of 117 tons, instead of the previous 105 tons, it is equipped with a crane strut with a hook block and a drilling mechanism for manufacturing a leading well or loosening with a screw in case of impossibility of indentation of piles in the upper sandy layers of the base.

In addition, this installation has a lever mechanism for clamping the tongue, allowing you to immerse and remove the steel tongue Larsen IV and Larsen V.

Currently, the USV-160M pile-indentation machine with a pressing force of up to 1600 kN is operating in the trust, and a machine with a force of up to 2000 kN is being finalized.



**Fig. 1.** Static indentation of piles using the USV-160M installation.

An important advantage of this technology is that prefabricated reinforced concrete elements are immersed in the ground, the quality of which is easy to control before the installation of piles.

However, it must be borne in mind that under certain ground conditions, in particular in soils with a strip texture, the immersion of piles can lead to additional deformations of the base and foundations of nearby (up to 3 m) buildings (according to the results of SPbGASU studies). This was the reason for the need to develop other methods of building foundations and improving the properties of soils.

So, to fix weak water-saturated dusty clay soils with a number of geotechnical companies, the equipment of the Italian companies Soylmek and Casagrande was purchased for the production of Jet Grouting technology. This technology allows the formation of a cement mass by supplying a fixing solution through a nozzle of a drill under pressure up to 600 atmospheres (Fig. 2 and 3). Using the inkjet technology, the Geostroy company performed fencing of the pit for the construction of an underground passage in the immediate vicinity of the Avtovo metro station, the construction of a vertical mine for

Vodokanal, the consolidation and stabilization of soils under nearby residential buildings and structures.



**Fig. 2.** Working body of the Soylmek installation for the production of inkjet technology.



**Fig. 3.** Example of fixing a soil mass using inkjet technology if it is not possible to fix the walls of the trench with a metal tongue.

The technology of fencing pits for buried and underground structures using the "wall in the ground" method has proven itself in foreign and domestic practice (Fig. 4).



**Fig. 4.** Soilmek installation to perform the "wall in the ground" grab method.

The equipment of the German company "Bauer" allows the construction of a wall in the ground using a milling cutter or grabs. The VS-40 cutter with three-row incisors allows you to work on grips up to 3 m long. With a mass of 80 tf, such equipment can work effectively both in dusty clay soils and in dense gravelly sands and moraine soils with inclusions boulders. It is believed that the performance of equipment with the BC-40 cutter is 2-2.5 times higher than the performance of a hydraulic grab.



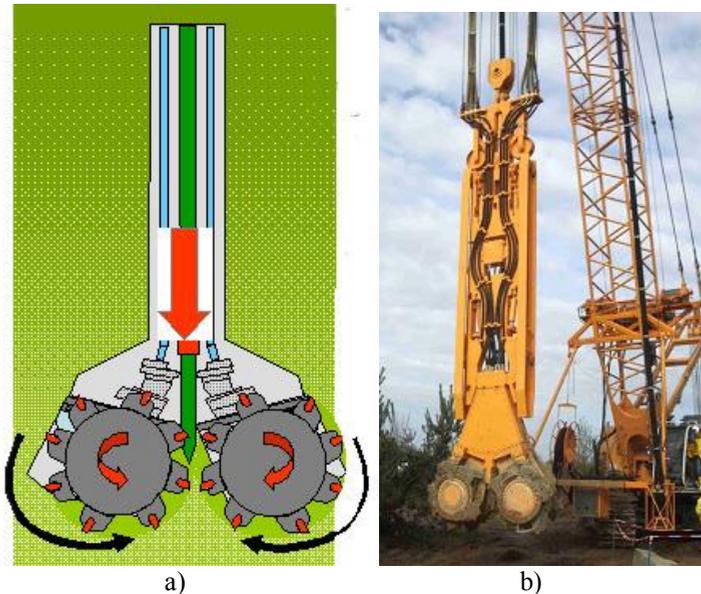
a)



b)

**Fig. 5.** Installation of the German company "Bauer" with the cutter "BC-40".

Taking advantage of the milling technology and the deep soil mixing system using inkjet technology formed the basis of the new Bauer development using the CSM (Cutter Soil Mixing) system. A drill string with a cutting-mixing action head goes deeper into the soil during drilling, the soil is milled in the process, but it does not recover. Cement mortar flows through the installation pipe and is mixed with the soil using wheels and baffles, which act as a forced mixer.



**Fig. 6.** CSM milling and drilling installation.

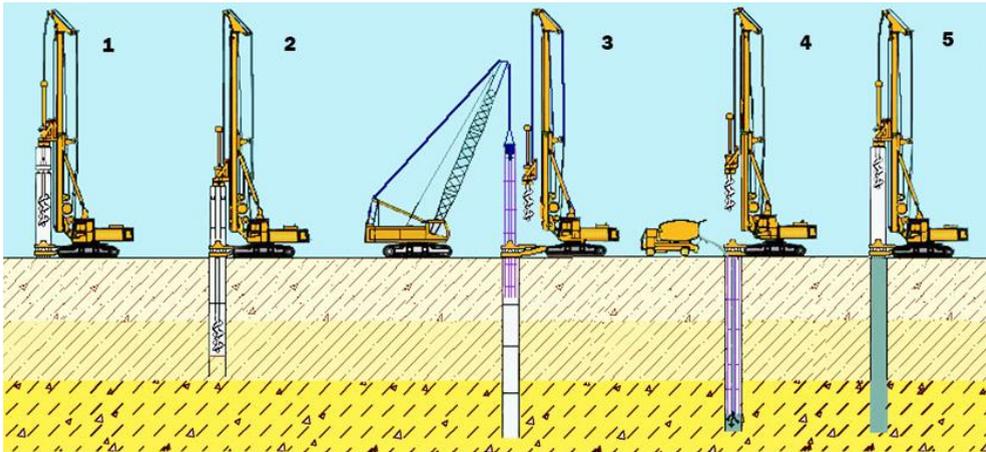
The previously well-known technologies for manufacturing piles in the ground - drilling, bored and injection piles from the beginning of the 90s in St. Petersburg received a new life and greatly reduced the percentage of use of prefabricated piles (prefabricated reinforced concrete piles).

By the nature of the manufacture, such piles can be divided into 3 main types: piles with excavation, with partial excavation, and without excavation along the shaft of the pile.

#### 1. Piles manufactured with excavation.

Briefly, this technology is as follows: a) immersion of the protective casing; b) soil development inside the shell with a screw; c) immersion of the reinforcing cage and filling the well with concrete by the vertical pipe transfer (VPT) method with simultaneous casing hoisting.

For this purpose, domestic installations based on domestic drilling rigs of the LBU-type and foreign Bauer, Yuntann, Kazagrande, Soilmec, and others are used in the city.



**Fig. 7.** Technological scheme for the implementation of piles under casing protection: 1- installation of the drilling machine at the drilling point; 2 - immersion of the casing pipe to the design level; 3 - immersion armokarkas in the well; 4 - filling a well with concrete from a car mixer; 5 - extraction of the casing pipe.

For the construction of bored piles up to 50 m long and a trunk diameter of up to 1200 mm, domestic companies in St. Petersburg successfully use Bauer machines. The extender, specially used in some cases, makes it possible to produce bored piles under the protection of casing pipes with a broadening diameter of 620-1200 mm, which provides a significant increase in the bearing capacity along the tip and a more complete use of the bearing capacity of the piles on the material. Testing of bored piles with broadening showed that the bearing capacity of such piles on the ground is 50-70% higher than piles without broadening.



**Fig. 8.** Construction of bored piles 18 m long on Vladimirskaia square.

Another variety of this technology is the development of soil under the pile body under a clay solution that protects the walls of the well from collapse and spillage and is

subsequently displaced by the concrete mixture. Subject to the observance of technological parameters and the assignment of small and adjustable values of rotation of the drill, the acceleration values transmitted to the ground and foundations of neighboring buildings are very small and not dangerous for neighboring structures.

Note that in the manufacture of piles according to the indicated technology, attention was repeatedly paid to a significant increase in the bearing capacity of piles tested by the static load in comparison with the calculated one according to existing standards. This, in particular, can be explained by the increase in the diameter of the pile shaft during their manufacture in weak clay soils. Obviously, this issue requires further study with changes in the relevant regulatory documents.

## 2. Piles made with partial excavation.

These include: straight screw method (CFA), Double-Rotary technology, SOB technology.

So technology according to the method of a hollow screw provides for the following:

- a) hollow screw is screwed into the depth of the future pile;
- b) screw with rotation rises with a part of the soil and at the same time concrete is uploaded into the well through its internal cavity by the concrete pump;
- c) frame is immersed into the concrete using a vibrator after removing the screw.

A feature of the Double-Rotary technology is that the rotation of the continuous straight screw takes place inside the casing, which moves in the opposite direction. This allows you to significantly increase the productivity of manufacturing piles, to ensure the safety of work in the vicinity of existing buildings. For these technologies, a prerequisite is the availability of a powerful concrete pump with a capacity of at least 60 m<sup>3</sup>/hour.

## 3. Piles made without excavation.

According to this technology, piles DDS-“Bauer”, “Fundex”, “Vibrex”, “Atlas” are performed.

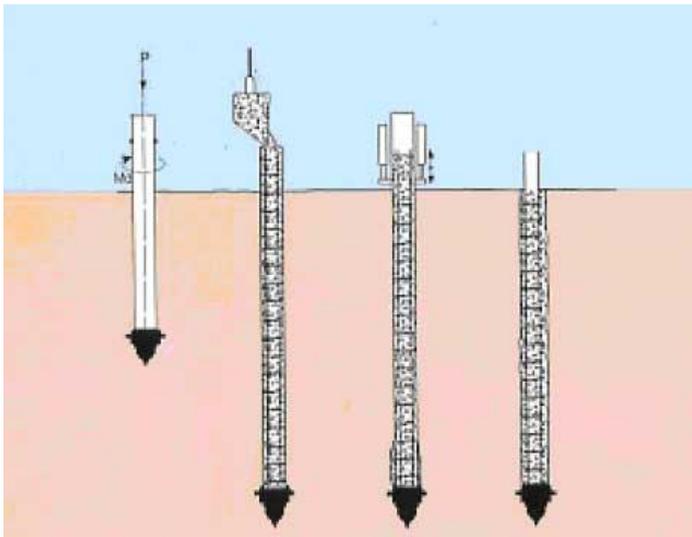
With the DDS technology, there is no excavation due to the use of a special working body, which compacts the drilled soil to the sides (Fig. 8). Upon reaching the design level through a concrete pipe located in the body of the rod, the concrete is supplied with the simultaneous rise of the working body. The working body performs the function of a packer bursting a well, and does not allow concrete to rise higher. The armature frame is immersed in the body of the completed pile using a vibrator.



**Fig. 9.** Well performance using the DDS technology.

A technological feature of compaction piles (screw-in piles) is the immersion of the casing with the end to be left, which allows the concrete mix to be immersed in a deliberately dry face while observing the appropriate technology. The following main technological operations are carried out:

- a) the casing with the lower tip to be lost is immersed (by a vibro-diesel or hydraulic hammer) or screwed into the ground with a large torque moment and axial load to the design elevation of the pile heel;
- b) an armature frame is installed in a submerged pipe and the concrete mixture is pumped;
- c) the pipe is removed by counter-rotation and vertical pulling force of the cables. In this case, a cast-iron or steel tip remains in the ground.



**Fig. 10.** Fundex pile technology.

The diameter of the piles is 350, 450, 520 mm and a length of up to 35 m. The bearing capacity, depending on the type of foundation soil, is up to 2500 kN. Productivity up to 100 r.m. per shift. Under specific ground conditions, in particular with dissimilar soils (incoherent in the upper part of the base, underlay, cohesive soils below), defects may appear during the production of such piles, in particular, thinning of the pile shaft (Fig. 11).



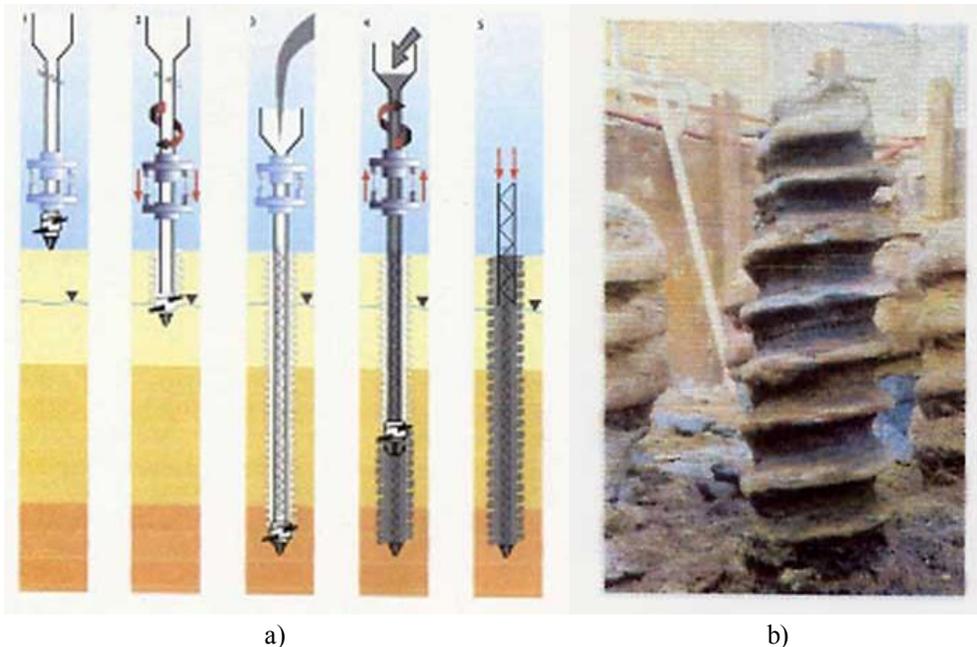
**Fig. 11.** Defects in the body of bored piles made according to the Fundex technology.

For several years now, in St. Petersburg, the Geozol company, using Belgian technology, Atlas bored piles widely known in Europe has been carrying out. The procedure for installing such piles includes:

- 1) screwing the pipe with a screw cutting tip to the design mark;
- 2) installation of armature frame;
- 3) return lift with rotation of the pipe with a screw tip for simultaneous concreting.

High exhaust forces, up to 800 kN, combined with high torque during drilling, is one of the important features of the modern Atlas drilling installation, which allows obtaining a screw-shaped pile.

Diameter of the used cutting tips: 360; 410; 460; 510 mm, the resulting diameter of the helical surface: 530; 610; 670; 720 mm. Productivity is up to 15 piles per shift.



**Fig. 12.** Atlas pile technology (a) and view of finished pile (b).

Note that in the conditions of weak soils of St. Petersburg, obtaining a spiral surface of the pile shaft is problematic.

#### Bored piles using electric discharge technology.

The discharge-pulse technology of piles used for compaction of concrete mix in the bottom of the well allows to obtain high strength indicators of concrete of the pile shaft and in certain types of soils, helps to seal the walls of the well, which in turn affects the bearing capacity of bored piles. This type of pile is rational for use in cohesive, low-moisture soils of a refractory texture. In weak soils, with an electric discharge in the inside of an unhardened cement mixture, it is possible to swim in a pile body of water-saturated soil with the formation of defects in it or interruption of sand concrete.

#### Bored injection piles.

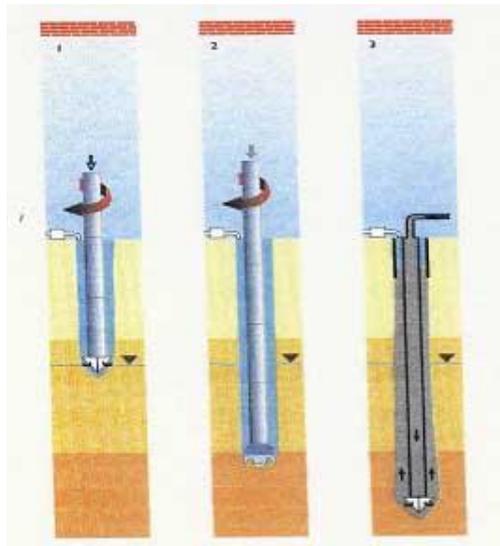
As a rule, they are used to strengthen existing foundations of buildings during their reconstruction or superstructure. The most common diameter of such piles is 150-280 mm with a length of up to 15-20 m. Cement, cement-sand, cement-bentonite mortars are used for the construction of such piles.

The technology of bored injection piles includes: drilling a well, filling it with a solution, installing armature frame and crimping it with a solution under a pressure of 0.2-0.3 MPa.

Well drilling is performed by rotary drilling machines under the protection of casing or clay mixture.

Using the technology of bored injection piles, the foundations of the Church of St. Catherine (Cyclone), the Tauride Palace (Geostroy), Derzhavin's estate, and many other objects in St. Petersburg and the suburbs were strengthened.

One of the modifications of the technology of the construction for bored injection piles is the bored injection piles “Franki” or “Titan”. Their characteristic feature is the passage of the well using an abandoned chock and a protective pipe that plays the role of reinforcement. Cement-sand mixture enters not only the casing, but with an increase in the supply pressure of the mixture flows around it from the outside, compacting the soil. This technology was used by Geoizol company to strengthen the retaining walls of the terraces of the Menshikov Palace in Oranienbaum.



**Fig. 13.** Scheme of the construction for bored injection piles using the Franki technology.

It should be noted that in the difficult soil conditions of St. Petersburg, it is almost impossible to provide piling device technology that is completely safe for neighboring buildings. Work experience shows that the installation of piles for a new structure at distances up to 2 m from an existing building can lead to additional deposition, and sometimes to an increase. The magnitude of the additional induced deformation of the structure foundation depends on the characteristics of the soil base, the chosen method and technology of the work, the design and condition of the neighboring building, the experience and qualifications of the construction company's specialists and other factors. Obviously, all work related to the installation of pile foundations in a compacted construction should be carried out with constant geotechnical monitoring - geomonitoring by specialized organizations.

#### Inference.

Currently, the construction market of St. Petersburg is represented by a fairly large number of companies specializing in the construction of various types of foundations, including pile ones. They offer various execution technologies, various quality and prices of piles. The customer is faced with a difficult choice of the most rational and safe technology and construction of piles. This choice should be made depending on the specific geological and hydrogeological conditions, the scheme and construction of the created or reconstructed building, the surrounding buildings and its technical condition. Substantial assistance in this choice should be provided to the developer by geotechnical specialists at all stages of the development and maintenance of the project.

## 4 Conclusions

1. The presence of a large number of different technologies for the manufacture of piles, often puts developers before a difficult choice, in which it is necessary to take into account a large number of different factors - the design of the facility being built, the specific engineering and geological conditions of the construction site and of course the cost of the work.
2. For many new technologies, the regulatory and technical framework is still insufficient. Their information support is also lagging behind.
3. Developers and investors, sometimes do not know the advantages and disadvantages of one or another technology for manufacturing piles and the limits of their applicability, often dwelling on the cheapest offers, which do not always ensure the reliability of the future foundation.

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