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Features of Piling and Their Interaction with Soil

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Abstract

In Belarussian geotechnical practice, there are often problems in the design, installation and testing of piles. These problems arise from incorrect knowledge of how piles interact with different soils. In this article, the authors propose solutions to such problems for improving the efficiency of pile foundations. The practical experience accumulated in the Republic of Belarus can also be useful for Iran and Iraq, where similar ground conditions occur during construction.

Keywords: construction, geotechnics, jacking, piling, safety engineering, structural safety

1. Introduction

Piles are the oldest types of foundations that primitive man drove into the bottom of reservoirs while building dwellings on water. They are a kind of long and slender structural foundation used to transmit foundation loads through soils of low bearing capacity to a deeper strata having high bearing capacity; however, there may be weak soils on the surface or at a deeper level at the same time. Pile foundations are used in construction and reconstruction carried out in difficult geological conditions, and are used in the construction of multi-story buildings as well.

Nowadays, there are many kinds of pile designs and technologies. In technical literature, and codes, pile classification is described according to various characteristics, such as the composition of the pile foundation, the shape of the pile in longitudinal and transverse sections, the method of installation, and the methods of their construction.

Clearly, piles can transfer into the ground various loads as vertical compression or uplifting, as well as lateral and moment forces. In this regard, it is important to know how different piles interact with different soils. Understanding such features and making the right decision regarding the design of the piles based on the dynamics and kinematics of the force effects will help us to avoid many of the errors encountered – avoid many mistakes and problems – when constructing them. This article shows the features of the pile behavior under axial load. The research is based on the practical experience of the authors.

2. Pile be driven into the ground (driven piles)

Reinforced concrete piles are the most common piles. The features of their interaction with the soil will be considered

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according to two classification criteria. The soil can take (perceive or withstand) compressive and shearing stresses. In geotechnics, usually two types of piles are described depending on the manner in which the load is transmitted into the surrounding soil. In the first case, the important point is that the soil resistance is derived primarily from skin fraction or adhesion between the embedded surface of the pile and the surrounding soil. Such piles are often called "**floating pile**", but this definition does not show the essence of the interaction of these piles with soils. The ground surrounds the piles, around the perimeter, and prevents their bending from contraction. Also, it would not be true to called such piles "**friction piles**". Friction piles have soil resistance only along the surface of piles body, while the resistance of the ground below the lower end of the pile is more important. Based on this, the normative literature of the Republic of Belarus and of most foreign countries use a more appropriate term "be captured piles by soil" in such piles. In the second case, the soil friction resistance at the pile tip. If there is no soil frictional resistance along the pile body and most of its carrying capacity is transferred to the relatively incompressible stratum, below the lower ends of the piles, then these piles are called **end bearing piles**.

Prof. Lapshin F.K. suggested distinguishing the following two important classification characteristics of any type of piles interaction with surrounding soils. These signs are based on the features of the piles installation:

- Piles are formed by displacing the soil around the piles shaft;
- making piles by driving a cylindrical steel shell into the ground, then excavating soil from it.

The first case is characterized by installing precast concrete piles into the ground in different ways by driving, vibrating, and by jacking. Also, the soil is displaced when concreting the cast-in-place piles, which are formed by driving a cylindrical steel shell into the ground, and then filling the cavity of the shell by fluid concrete or by pipe piles which are usually driven with a conical tip at the pile tip.

The second case is typical for piles, which are formed in pre-bored holes in the ground and then filled with concrete. As a result of this process, the soil is partially loosened on the walls and sludge is accumulated in the bottom of the boring hole.

There is an erroneous opinion about compacting the soil and about the physical processes taking place in this process when displacing. This opinion was refuted by Prof. Nikitenko M.I. together with his students [1], because when expanding the soil around the well, the compressive stresses are distributed in radial directions and promote the compression of the soil with a gradually decreasing intensity. In this case, along the circumferential directions, tensile stress causes a repackaging of disconnected sandy particles and rupture cracks between the connected clayey soils with decreasing their adhesion.

The impulsive dynamic effects the sandy soils during the pile driving and repackaging of particles contribution that loosen in the upper layers with compaction at the lower ends, but this effect does not appear in the cohesive soils at deeper levels. In piles with cylindrical cross sections, the processes of compression and extension of the displaced soil in circumferential directions are distributed evenly along the contour, but in rectangular sections with stress concentration at the angles, discontinuous cracks after the installation of piles are possible at the surface even in sands (Fig. 1). In clayey soils, the particles are also repackaged in combinations of their compression and shear pressure, but from the expansion, brittle fractures with a noticeable decrease in adhesion from the breakdown of structural bonds become more pronounced.

In recent years, in many countries, geotechnical practice was dominated by driven piles due to their rapid installation and the achievement of soil compaction when it was displaced around the pile shaft. However, the significant **drawbacks** of such piles should not be forgotten: the limited bearing capacity on the ground for small ranges of lengths and cross-sections of shafts, negative friction resistance along pile surfaces, harmful dynamic effects on adjacent objects during hammer striking in driving methods. Without leader holes or jetting's method [1...], precast piles could not be installed to design marks, especially in sands, which inevitably causes the so-called "pile forests" situation (Fig. 2).

Figure 1. The gap between sandy soil with rupturing cracks in the corners when the pile body is tilted from misaligned hammer impacts during pile driving

Figure 2. Not be driven to design marks of piles

The process of cutting off protruding sections of piles is laborious and even dangerous. There was a case when even the helmet did not prevent the accident from blowing a piece over the worker's head.

To exclude such an entrenched, perverse practice, determined its causes. Workers cannot load the piles at the required depth, cut the upper parts of the piles and consider that the piles have plunged to the maximum possible depth and do not load any more when the hammer strikes. However, they do not take into account the possible interactions of piles with soils.

Commonly, piles to not be loaded onto design depths when a thin solid layer of hard soil is encountered in the overlying the mass of the base, in which the erroneous design failure value may be reached prematurely. In this case, the remaining thickness of such a hard layer during punching can be pierced during operation and then the lower end will be in a low-strength massif.

The amount of refusal (the term itself is unsuccessful), i.e. driving piles with one hammer blow or one minute of vibration can exposure because of:

1. **the pile's jamming** into coarse sandy soil with dilatant unfolding particles in the shear along the contact zone along the pile shaft;
2. **the pile's slipping** after the jamming is due to the rotation of soil particles because of contracting and a decreasing in the volume of the shear zone along the pile shaft with a decrease in soil resistance;
3. **the pile's saponification**, clayey soil becomes plastic and slippery like soap, as the soil turns into a flowing state due to the transformation of the connected water into a free from shocks. Thus, the resistance to shear along the pile stem and under the lower end of the pile falls.
4. **the pile's suction, i.e. when piles can themselves immerse into clay soils after the hammer blows have ceased. This occurs due to the appearance of a vacuum in the gap (empty space) under the lower end of the pile when lifting from the elastic deformations of the compressed pile shaft and surrounding soil;**
5. **deceitful (low) refusal** when pile cannot be driven at design depth due to air or water bubbles (trapped gases), which is formed at the end of the pile because of poor filtering of fine and silty sands, with large elastic strains from impact pulses;
6. **pile dancing** – when piles can sink very abruptly, speeding up and slowing down their immersion. This happens due to existing a boulder (big stone) under the tip of the pile or the pile shaft breaks. This process is accompanied by a characteristic roar (noise).

Small values of pile are driven with one strike of a hammer or one minute of vibration and an erroneous idea of the achievement of the required soil resistance are due to insufficient capacity (deterioration) of the equipment. To properly assess the resistance of the soil, piles must be immersed with hammer blows or a vibrator without excess weight, and make a break between impacts for a certain period of time. Also, during dynamic tests, should be paid attention to the behavior of piles and their interaction with soils.

One of the reasons for not thoroughly driving piles is an unsustainable distribution of the momentum from the impact (impact pulse) along the body of the piles. The energy of the impact pulse is expended on destroying the pile head and resisting ground pressure because of the large area of the lateral surface of the inclined pile shaft. This is due to a non-axial impact and therefore a very weak impulse reaches the end of the pile. Simultaneously, piles with the form of a pyramid are immersed (struck or hammered) to the design depth much better if the cross section of their shaft is reduced in proportion to the shock impulse and increase in soil resistance with increasing depth. Unfortunately, recently in the geotechnical practice of Belarus, using driven piles in the form of tapered was stopped, although these piles are more rational and economical in comparison with straight piles. Also, Belarus does not use piles in the form of belled drilled shaft and straight driven piles, which consist of hollow elements. Piles, the end of which in the form of a tapered very well take pulling forces in the case when they are installed as end bearing piles. Piles consisting of several empty elements can be used with an unsustainable surface of the ground and it is easy to immerse the lower ends of the piles to the desired projected depth. The disadvantage of these piles is that they cannot bear pulling, shear and moment loads.

Important advantages of tapered piles are:

- the absence of friction along the shaft of the pile;
- the soil is compressed along the entire length of the pile shaft with the inclination of the pile faces in a larger proportion;
- lower metal consumption for reinforcement, especially pile heads with increased cross-section;
- the possibility of driving a pile to the necessary design marks, since the cross sections are compared with the distribution of impact pulses when the piles are driven.

Practical experience shows that in any soil, the immersion of driven piles by means of vibration is more effective than piling with a strike. This is due to the fact that the vibration effects on the pile occur continuously. When the piles are pierced with shocks, the pulses alternate with each other at short intervals. When vibrating the soil particles along the trunks of the piles and with each other under the pile tip, they stop resisting piling the pile into the borehole, due to the lubrication with water. The water shakes under the influence of vibration and passes from the connected state to the free statement, and after the cessation of shaking the structural water-colloidal bonds on the surfaces of the soil particles are restored, as well as the general resistance of the soil around the piles.

To the precast piles relating the precast piles, piles in the form of metal pipes with screw blades at the end of the piles. They are driven with excavating soil from the well. These piles are mainly used for coaxial indentations and pulling forces, which are held by compressive forces in the ground below or above the pile blades.

3. Reinforced concrete drilled piles (cast in place piles).

The use of bored piles has many design and technological solutions, as there are many different types of soil, many options for soil layers and construction purposes. Modern scientific developments offer several types of bored piles.

Bored reinforced concrete piles with cylindrical shafts are the most commonly used piles. Such piles are created with the help of concrete in boreholes, while the soil can be extracted from the well or displaced to the sides. The body of such piles can be reinforced (fixed) along the entire length of the body of the piles or only the upper part of the pile's body. This reinforcement process depends on how the driven or pulling forces act with shear and moment forces. The characteristics of the ground and its features also affect the process of reinforcing the piles. Pile reinforcement does not apply only in the absence of bending deformations. Only in this case piles can be hollowed and have a solid section. But when they are under shear and moment loads, such piles may collapse. An example of the failure of prefabricated, hollow piles of reinforced concrete can be demonstrated by a case that occurred in China on June 27, 2009 [24]. A 13-story residential building fell as a result of a digging excavation for an underground garage on one side of the building and deputing the soil on the other side of the building along the river bank (fig. 3).

Figure 3. Collapsed in Shanghai, a 13-storey residential building [24] in the failure of prefabricated hollow reinforced concrete piles, weakly reinforced by tensile rods of small diameters

The construction technology of bored piles without displacement and compression of the surrounding soil [4] is the simplest. With this technology, a bore hole is drilled, then a reinforcement cage is placed and the concrete is poured. The shaft can be drilled with a conventional auger in the presence of strong soil. However, in the case of crumbling or unstable soils, it is necessary to protect the well with a casing or to using a bentonite suspension when drilling. If the wells are very deep, the concrete is poured into the well with the help of a special pipe. From this pipe, the concrete leaves through the lower end and rises upwards in the space between the pile (casing) and the walls of the borehole. If the diameter of the well is small and does not allow the immersion pipe to be immersed in it, it is necessary to feed the concrete through the casing or pump it through the hose of the concrete pump to the bottom of the well.

Prof. **I. Akhverdov** proposed a method for piles in saturated soils or restricted conditions of objects. This method consists in the fact that the casing is initially installed with the lost bottom plate being filled with stone. The grout is pumped upwards through the injector from the bottom upwards and the casing is gradually removed.

If driving bored piles is carried out in traditional ways, problems can then arise. Such problems include the occurrence of loose sediment (sludge) at the site of wells when they are drilled with auger. Also, the strength of the water-saturated soil that surrounds the pile can be destroyed. This destruction occurs under the pressure of water due to the difference in water levels outside and inside the well when it moves under the protection of the casing with an open bottom end. This leads to an underestimation of the bearing capacity of the pile bases due to the low resistance of the soils to compression under the lower ends. For example, we will give the results of tests conducted in a foundation pit for the construction of a high-rise building on the site of the former cafe "Recenka" at Pobediteley Avenue, Minsk (Belarus). Thus, testing one of the piles in water-saturated sands (with extraction of sand from the well) showed the value of a bearing capacity on the ground of only 750 kN. Therefore, it was proposed to improve the technology of the device piles by vibrating the casing, with the emergence of a condensed sand plug at the bottom (Fig. 4).

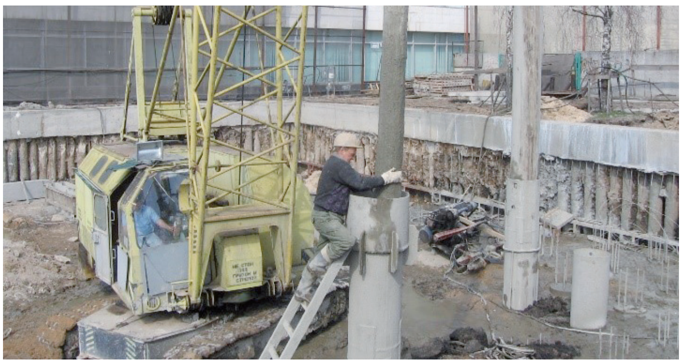

Figure 4. Structure of bored piles in saturated sands: on the left – installation the bailer for excavating from the casing of biogenic soils over the compacted ground plug to the right – its displacement by a second pipe with closed end

Figure 5. Drilling wells by drilling rigs of the firms «Bauer» and «Cassagrande» under the protection of casing pipes with scooping out of the ground by bailers and refilling of water into the casing

Figure 6. Concreting of piles in a casing filled with water by the method of VPT when pouring concrete from a mixer through the socket of a concrete pipe

Further, the upper ground layers of soil were removed from the casing. At the same time, the water pressure could not remove the sand plug. Then the inner tube with the closed end was installed by vibro hammer. This action allowed to remove the sand plug and transfer pressure to the pile up to 2700 kN. At the same time, in six experimental piles, the total settlement was from 16.5 to 24.5 mm with a linear increase in the transmitted loads.

Serious problems can arise during the construction of piles at great depths and large diameters of the pile's shaft in saturated sands. Especially when in the ground there is pure pressure between clay layers. This happened in the foundation pit for the construction of the high-rise building of **Gazprom** in Minsk (Belarus).

There, bored piles Ø 0.118 m were immersed in a carrier layer to a depth of up to 29.5 m. Wells were drilled using casing pipes with open lower ends. The ground from the pipes was removed by sludge-bailer (Fig.5), since the pressure water was between two layers of morainic sandy loam. Water was also added to the casing, as described in the manual [4]. For concrete piling of the piles under the water (Fig. 6), the method of the vertically moving pipe (VPT method) was used. But this affected the fact that the quality of the concrete at the top of the piles was very poor (Fig.7).

This situation was influenced by factors that were not taken into account:

- the water that filled the casing contained pieces of clay soil;
- a concrete mix for the construction of barrel piles was used with a cone draft of more than 18 cm. This is indicated in the VPT method. However, concrete poured out through the lower end of the pipe and mixed inside the well with water that contained clay. This greatly worsened the quality of concrete (or concrete mix);
- when leaving the end face of a concrete pipe into a wide gap between the casing, a highly liquefied and contaminated concrete mixture captured clayey sludge containing clumps of uncooked completely sandy loam of moraine and clayed sand, taking them upwards inside themselves under a head, faster by contact filtration outside the concrete pipe when lagging along the inner surface of the casing;
- The concrete mix was heavily filled with sandy clay soil to the top of the casing. Also, soil sludge from sandy clay was distributed unevenly throughout the length of the piles.

Inside the concrete piles there was a lot of rubbish from the sandy clay. This was determined when cutting off excess pile tops and found that the piles have a strength lower than the defined design. Throughout the depths of the piles were drilled with a diamond tool and also found lots of sections of clay and sand. This problem greatly slowed down the construction of the facility.

Unfortunately, the proposal of one of the authors of the article was not accepted. The author used an analogy both in the construction of trench walls [5]. He proposed combining

Figure 7. Defects of the heads of bored piles as a result of underwater concreting with cast concrete mixtures

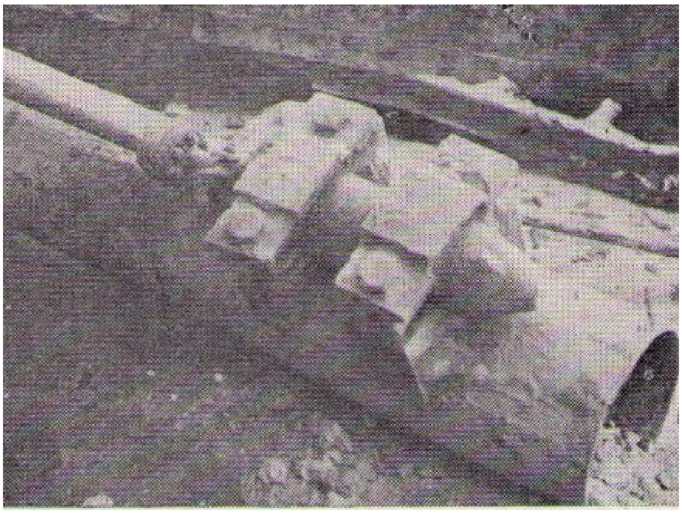

Figure 8. Equipped with a vibro bullet bottom concrete pipe

the VLT method with the vibrational feeding of thick concrete mixtures (with a cone draft of only 5–8 cm). Such a method [10] provides the following: at the lower end of the pipe through which concrete flows, it is also attached from above (outside) the vibrator head (Fig. 8), when switching on the thick concrete mixture is liquefied.

Connected water in the concrete mixture on contact with the pipe passes into the state of free water and becomes a lubricant. This lubricant helps to bring concrete down to the end of the well without mixing with clay soil particles (clay slurry) or with slurry. This solution also saves cement consumption up to 100–150 kg per 1 m3 of concrete mix. The strength of concrete is preserved and the process of its hydration is accelerated.

The unitary enterprise **"Institute BelNIIS"** proposed using embossed in the ground and concreted grills, together with conical piles of small size [7]. Employees of the department proposed the idea of using grillage [2] for soil compaction, solution pouring or pressure (tamped) under the soles of a dry concrete mix. Such a mixture drains plastic clay soils and improves their properties with an increase in the bearing capacity of the substrate.

To exploit the dignity that the soil is shifted to the sides and soil compaction, piles are poured into stamped holes [7] and bore injectors when injected into bore holes under the pressure of cement mortar [6] or cast concrete [17,23,26].

Grouted bored piles technology makes it possible to make the soil harder at the base of the piles with the help of soil compaction. The creation of broadening under the lower ends and along the trunks of the piles makes it possible to increase the total resistance of the soils. Also used shut-off pile walls. They protect against uneven sediment and excessive deformations of existing buildings and structures. The pile walls limit the zones of caving in the underground excavations or pits near existing buildings (Fig. 4).

Such designs have a positive effect due to reinforcement, creating obstacles for wave influences of noise and vibration in the ground. In the ground, anisotropic properties are created that dissect and absorb waves. These properties are enhanced by adding rubber waste, granulated expanded polystyrene or other resilient materials to the wells.

Pile stems with enlarged sections at the top and those widening under the lower ends of the piles ensure the same strength of the pile material and pile bases. Their models are created by injection and pressing the soil in the face [12]. Piles in the form of a wedge expand the zone of ground compaction and their use allows a reduction of the length of the trunks of piles, the boundaries of compression of the ground and eliminate negative friction. This is especially important in the presence of weak and biogenic soils at depth since air access to these soils can degrade the strength properties of the soil.

In recent years, pile piles have become very popular. These piles are built using casing pipes, which are immersed in a vibrator. In the lower ends of the pipes, lids or conical punches are installed (Figure 9).

Figure 9. Making holes for bored piles:
a – driving conical punch by using hanging vibratory,
b – driving cased shaft by vibrating, on the hard track machine ABI

Figure 10. concreting of the casing shaft by mixer

The technology of vibro hammers for inserting piles includes penetration equipment borehole that helps to drive steel casing pipes in the form of a conical or pipe with a special bottom plate, driving the reinforcement cage into it, filling the interior with concrete mixture (Fig. 10), and then pulling upward the casing at the same time using a vibrator for compacting concrete mixture and for and high quality formation of pile shaft in the hole (Fig. 11).

Figure 11. driving tapered casing by using hanging vibro hammer

The advantages of bored-vibrating piles technology by driving a cased shaft with losing the plate at the end are:

- High speed and simplicity of operations;
- Ability to carry out piles in different geological conditions, regardless of the ground water table due to the choice of rational methods of boring holes, to concrete shafts and rammed vibrating concrete with expansion on their toes;
- High quality of concrete piles by vibration and filling the shaft with concrete mixes, thus it may have the best water-cement ratio, good mobility, and does not rusting during interaction with groundwater;
- The ability to assess the bearing capacity of piles according to [2] in designing depth by measuring the rejection value during driving the case with a vibrator with losing the plate on the end or ramming of the pedestal under the toe;
- the last advantage is the ability to reveal undiscovered zones of weak soils between the exploratory excavations (boreholes and penetrating points) and promptly take the necessary steps to provide the perception of design loads on pile foundations and increase maintenance safety for over ground structures.

By drilling boreholes through the filled and organic soils until bearing deposit, an excavation is required to prevent filling it into the pile toe. In such cases, the casing must dive with an open end. Weak organic soils removed by bailer and impacted the plug then pulled downward by means of the interior pipe with closed-end. By using this punch, we can extend the toe (Fig. 12) by filling the portions of dry concrete mix to outer casing pipe. The dry mix under the pile toe drains clay soils and improves their properties.

If the inner tube is sharpened, the concrete mixture that is compacted by it will flow around the outer surface of the pipe when displaced, and the resulting broadening will acquire

Figure 12. the cases-punch with butt plugged end and excavated rammed pedestal under the pile toe

a vertically elongated shape with a decrease in the transverse dimension. This was confirmed by the device of an experienced pile in the sand under a multifunctional building on the street. Timiryazev, at the test of which the base load capacity was lowered by half compared to the design value. As can be seen in Fig. 12, at the flat end of the bottom plate of the casing, the broadening appeared flattened with an increased diameter, which ensured the achievement of the required ground resistance under the heel. It is enough to simply broaden the bottom ends of bored piles in order to create by injection when injecting solution under pressure at an appropriate level along their trunks.

In this case, the cement slurry drains excess water in the sands and quickly gains strength, but in clay soils, the hydration process is excessively prolonged and can last even several months without access to drainage air, worsening the properties of the surrounding soil due to its additional moistening. Therefore, it is preferable to pump the polymer mixture Uretek [20, 21, 22], which is able to increase its volume several times, while creating pressure for pressing the concrete mix of the pile shaft and the surrounding soil mass. In this case, this mixture hardens within 15–20 seconds and gaining strength in 10–15 minutes without additional soil moistening. It should be noted that traditionally pierce shafts of piles with casted mixtures, when immersed by vibro hammers and then with pipes, poured the cement although they are advisable to use more rigid ones, which is especially important in saturated and clayey soils.

The advantages of the performance technology of the bored-vibrations piles in weak clay soils in the presence of high levels of underground water, were notably manifested on the project “Cultural and Wellness Center and also Hotel in the Novovilenskaya street and the Kanatnavo alley in Minsk,” where one of the authors performed scientific accompaniment of the zero cycle to work with correcting the design and technological solutions.

At the time of driving with vibro hammers the steel pipes, with losing the plate at the end of pipe, to final depth was possible to predict the bearing capacity of the soil at the tip of the pile [22] by the value of rejection, i.e. pipe settlement in meter per minute by vibratory influence at a known mass and the forcing frequency (equivalent calculated energy).

Even in the time when there was a lack of enough bearing capacity at the projecting depth, we could refuse to continue driving more steel pipes (cased shaft), and increase the overall resistance of the soil due to the ramming of the pedestal under the toe. To do this, it was enough to fill at about meter interval by dry (zero slumps) concrete mix in a cased shaft cavity and ramming it out of the casing base about half a meter to produce an adequate-sized base enlargement until getting the rejection value of the project according to [2].

Since, at the time of boring, the wells have measured the rejection value from diving cased shaft, with losing the plate at the end, it was possible to determine the value of bearing capacity of the soil at the base of all the piles (there were a few thousand in the object) and allowed them to load. To do this, the relevant calculations were performed, and plotted

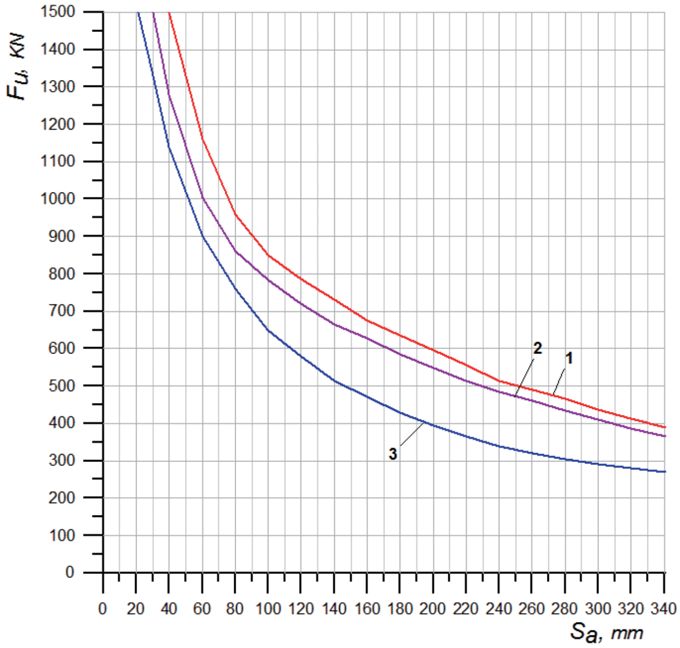

Figure 13. Depending on the resistance of the soil failure Fu v. rejection of steel case Ø 426 mm lengths of 10 m with the pile point vibrator with the parameter:
1 – m_1 = 4,0 ton при E_d = 405 KN, 2 – m_1 = 3,5 ton при E_d = 310 KN,
3 – m_1 = 2,5 ton при E_d = 865 KN
(m_1 – Mass of vibro hammer, ton;, т; E_d – Calculated energy of the vibrator, kN, determined from Table. 7.4 [3], depending on the disturbing force)

the soil resistivity by the rejection value whilst driving the case shaft by using vibrators (Fig. 13).

Such method has allowed identifying several areas with low soil resistance, which was not detected between the boreholes on lithological profiling according to the exploration. The necessary measures to ensure the perception of design loads on pile caps were taken in these areas.

By using the Continues Flight Auger (**CFA) technology** at the time of installing bored piles with Italian equipment in all types of ground helps compacting the surrounding soils of pile’s shaft, even in saturated soils, and wells are drilled with a continuous flight auger (Fig. 14, a), through which, with the lifting into the well is pumped under pressure from the grout mixer (Fig. 14, b), and in it immediately reinforcement cage is immersed to the required depth. An important advantage of this technology is high-speed pile devices, and compressing of soil under pressure along the shaft helps eliminate sliming and to achieve a higher bearing capacity of foundation. (Fig. 14, c)

The piles that are customized for this technology are called boron-pressed piles, which are a type of grouted bored pile [2], and their interaction with soils when pressed is similar to other species arranged with displacement of soil in the sides.

When installing walls from intersecting trunks of piles or, in the case of the need of their compact groups, for the use of a similar technology of drilling and concreting, double drilling machines are used with a combination of casing pipes and a hollow auger along the CSP (Cased Secant Piles – Secant piles with casing) system inside them (Fig. 15).

The main disadvantage, even with many advantages, of these two technologies (CFA and CSP) is the complexity

Figure 14. Equipment for piling CFA: a – drilling rig with a solid hollow auger, b – drilling rig for excavating of wells; c – lifting of the auger and installation with the vibro hammer after that installation the reinforcement cage

Figure 15. Drilling rig for execution of the pile system CSP

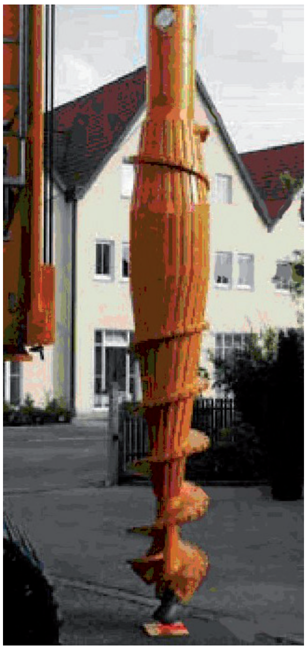

Figure 16. Bayer displacement drilling system

of immersing large reinforcement cages in concrete filled wells by intensive drainage of the concrete mix in sands and rapid thickening. With this, retarders are required in the concrete mix, which reduce the water loss and slow down their setting on the diving time of the reinforcement frames.

When adjusting the flow rate of concrete and the generated pressure of its injection, it is possible to create broadening under the lower ends and along the length of the pile shaft, and, if necessary, they can be tapered. The use of a spreader (Fig. 16) will additionally displace concrete and soils in the walls of wells with their crimping, thereby creating even the required broadening and coaxial cavities, which will save concrete consumption on the formation of shaft with an increase in the total resistance of the soils around the piles.

The drilling of wells with the erosion of the ground under the head of water pressure was first used in Minsk in 1982 for the construction of brown pile piles, providing hardening of loose sand lenses at the base of the foundations of a number of objects. More advanced methods of jet technology became possible due to the purchase of special imported equipment. (Fig. 17, Fig.18). According to this technology, piles Ø 0.8 m were made [19] to a depth of up to 25 m for

Figure 17. Piles for end support cableway lift snowboard in Silich by inject technology (in the background can be seen the machine company «Kasagrande» to perform pile)

the terminal support of the lift on the slope of the ski slope in Silich (Fig. 17). Then it was used on other sites. This technology also makes it possible to create the required sizes and shapes of the piles by adjusting the parameters of the high-pressure injection (pressure, velocity of rotation and rotation of the monitor, flow rate) of the cement slurry, but it is necessary to immerse the reinforcing cages after the creation of the piles with the inherent lack of this in the sands. More importantly, clay soils, with mixing, are not capable of gaining strength even after more than six months, as it was in Uruch'e.

In order to shorten the time of static tests of piles caused by a set of strength concrete, one needs to test steel pipes before their mass production, from which the outer casing serves as a shifted trunk, and the inner casing compresses the ground under the fifth pile (Fig. 19) with the tapered end. This eliminates the need in very large anchorages setup test, it takes two times less load capacity of the loading hydraulic jack, and separately it is possible to fix the soil resistances to shear along the trunks and compression under their lower ends. This approach is reflected in [4] as applied to the production of bored piles in place.

If there is a strong difference between one of the two types of soil resistance, it is necessary to load the casing or transfer the additional compression to the ground through the outboard side plates on the surface.

4. Conclusion

There are many geological and hydrogeological features of the soil, as well as many types of piles and the purposes of their application. Knowledge of the behavior and interaction

Figure 18. The equipment of Italian company Soilmec for inject technology

Figure 19. Testing of piles on the principle of «pipe in a pipe»

of different piles with a variety of soils will allow us to make the right engineering decisions, avoid many problems and improve the efficiency of pile foundations for new buildings and reconstructed structures. The practical experience accumulated in the Republic of Belarus will also prove useful for Iran and Iraq, where similar ground conditions are encountered in construction.

Bibliography

[1] TKP 45-5.01-45-2006 (02250). "Foundations and underground structures, constructed with the use of jet grouting technology". Design rules and devices. – Minarchstruc RB. – Minsk., 2006. – 33 p.

[2] TKP 45-5.01-254-2012 "Bases and foundations of buildings and structures. The basic rules construction standards of designing." – Minarchstruc RB.– Minsk. 2013. – 137 p.

[3] Guidance П2-2000 to building codes CNB 5.01.01-99. "Design of driven and cast-in-plase piles according to the results of ground sounding."– Minarchstruc RB.– Minsk., 2001. – 23 p.

[4] Guidance P 13-01 to building codes CNB 5.01.01-99 "Design and construction of bored piles" – Minsk 2002. – 43 p.

[5] Guidance P 14-01 to building codes CNB 5.01.01-99. "Design and organize the pile and wall in trench."– Minarchstruc RB. – Minsk., 2002. – 64 p.

[6] Guidance P 18-04 to building codes CNB 5.01.01-99. "Designing and construction of injection anchor and piles."– Minarchstruc RB.– Minsk., 2005.– 79 p.

[7] Guidance P 19-04 to building codes CNB 5.01.01-99. "Designing and construction of foundations formed from cast in place piles with compacted base." – Minarchstruc RB.– Minsk., 2006. – 88 p.

[8] CTB 2242-2011. Soil Field test methods by piles. – Minarchstruc. – Minsk., 2012. – 36 p.

[9] Akhverdov I.N. Temporary instructive instructions for separate concreting of massive structures. – Rustavi, 1952.

[10] VSN-261-74 / Minmontazhspetsstroy USSR. Instructions on the vibratory laying of concrete under water by the VAP method. – M., 1975. – 75 p.

[11] Grutman, M.S. Pile foundations / MS Grutman // Budivelnik. – Kiev, 1969. – 191 p.

[12] Lal Sudhir Kumar, Injection hardening of the foundations of drilling pile injectors: dis. cand. tech. Sciences: 06.01.02, 05.23.02 / Lal Sudhir kumar; Bel. state. polytechnical. acad. – Minsk, 1993. – 143 p.

[13] Lapshin, F.K. Calculation of the bases of single piles on a vertical load: dis.... Doct. tech. Sciences: 05.23.02 / F.K. Lapshin; Saratov. polytechnical. in-t. – Saratov: publishing house of the Saratov University, 1987. – 469 p.

[14] Mohammad, H.M. Buroinjection hardening of the foundations of buildings and structures under reconstruction: dis.... cand. tech. Sciences: 05. 23.02 / H.M. Mohammad. BSPA. – Minsk, 1998. – 196 with.

[15] Nikitenko, MI Modern geotechnical technologies in construction and reconstruction in Belarus / MI Nikitenko // Building science and engineering. – No. 4 (7). – Minsk, 2006. – P. 68–72.

[16] Nikitenko, M.I. Grouted bored anchors and piles for the erection and reconstruction of buildings and structures: monograph / M.I. Nikitenko. – Minsk: BNTU, 2007. – 380 p.

[17] Nikitenko, M.I. Methods for determining the bearing capacity of bored piles using CFA technology. Nikitenko, S.B. Moradi, N.V. Chernosha // Building science and technology. – 2008. – No. 1 (34). – pp. 43–49.

[18] Nikitenko, MI Some Problems of Pile Foundations in the Geotechnical Practice of Belarus / MI Nikitenko, V. Yu. Zhuravsky // Building Science and Engineering.- Minsk, 2008. – No. 4 (19). – pp. 44–51.

[19] Nikitenko, M. Use of polymer mixtures for soil stabilization in the bases of local highways during their reconstruction, repair and maintenance / M. Nikitenko, I. Boiko // Architecture and construction. – Minsk, 2018. – No. 1. – P. 45–49.

[20] Nikitenko, MI Jet technology in the geotechnical practice of Belarus / M.I. Nikitenko, AA Klyuyko // Geotechnics: Actual Theor. and practical problems: intercollegiate thematic collection. SPbGASU. – St. Petersburg, 2006. –? p.

[21] LLC "Geopolymer" is the official licensee of URETEK technology in the Republic of Belarus. https: / uretecbelarus.com.

[22] Baryłka, A. (2017) „Issue of building structures necessary for the purposes of state security and defence in the provisions of the act – on spatial planning and development." IBOA 2.

[23] Baryłka A., Periodic inspections of building objects in the process of their operation. Wyd. 2, Expertise Center Building, Warsaw, 2018.

[24] Baryłka A, Construction expert's guide. Part 1, Technical and legal problems in the diagnosis of construction works, Expertise Center Building, Warsaw, 2018.

[25] Nikitenko, M.I. Prediction of bearing capacity of vibrated cast in place's piles under dynamic load tests / M.I. Nikitenko, B.Moradi Sani // Vplyv vody na geotechnicke konstrukcie/ Zbornik 11. Slovenskej geotechnickej konferencie. – 3.a 4 Juna 2013, Bratislava, Slovenska republika. – p. 381–386

[26] Nikitenko, M.I. New technologies of pile apparatus and their test in ground conditions of Belarus/ I.L.Boiko, B.Moradi Sani, N.V.Chernoshey / New technologies of pile apparatus and their test in ground conditions of Belarus // Baltic piling: Proc. Of the conf. on Baltic Piling dais 2012. Tallinn, Estonia// CRC Press/ Balkema. 2013 Taylor & Francis Group, London. – pp. 77–88.