Interaction of screw piles with the base

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Abstract. The article presents the results of the practical applications of screw piles foundations for block quick-assembly buildings and buildings made of a metal frame. The results of experimental and theoretical studies of foundations in various ground conditions are presented. A method for estimating the stress-strain state of screw pile foundations using nonlinear calculation methods is proposed. The influence of pile length and blade diameter on the change in displacements and load-bearing capacity in cohesive and non-cohesive soils on the effect of pushing and anchor loads is revealed. The nature of the distribution of stresses and deformations at the base of foundations made of screw piles is revealed. The article is useful for engineers, specialists and researchers in the field of soil mechanics, foundation engineering and geotechnics.

1. Introduction
Screw piles are widely used in transport, industrial and power grid construction, as well as for the construction of military engineering structures. Bridges, overpasses, and power transmission poles were built with the use of screw piles. There are known cases of using screw piles with a steel trunk with a diameter of 1.02 m and a blade diameter of 2.2 m, up to 36 m long, as the foundations of a bridge across the Dniester River [1].

Foundations of this type have proven themselves well, so they have become actively used in civil construction. Their main advantages include the following:

- the high speed of construction;
- the possibility of arrangement in the ground of any type (except rock);
- high reliability, low cost.

2. Screw piles design for building foundations
Design investigations of screw piles, machines and mechanisms for dipping them in the ground, studies of the interaction of piles with base engaged by Akopyan V.F., Bartholomey A.A., Bakholidin B.V., Bogorad L.Ya., Gotman A.L, Zhelezkov V.N., Ilyichev V.A., Irodov M. D., Lebedev S.V., Luga A.A., Mangushev R.A., Mariupol L.G., Nuzhdin L.V., Penchuk V.A., Polishchuk A.I., Ponomarev A.B., Ponomarenko Yu.E., Trofimenkov Yu.G., Murashev A.K., Perko H.A., Rao S.N., Prasad Y.V.S.N., Mitsch M.P., Clemence S.P., Hoyt R.M., Zhang D.J.Y, Weech C.N., Pack J. S. and others.

The analysis of the works of national specialists shows that the research is mainly focused on the development of screw pile structures that reduce the energy intensity of the process of screwing them...
Often, the use of large-diameter screw piles for bridge supports and industrial structures is accompanied by problems associated with insufficient power of hydraulic rotators, which increases the time of work and reduces the efficiency of using these structures.

Bogorad L.Ya., Zhelezkov V.N., Lebedev S.V., Kravtsov V.N., Pinchuk V.A. Clemence S.P., Perko H.A., Hoyt R.M. and other authors were engaged in experimental and theoretical work related to the study of the influence of various factors on the resistance to immersion of screw anchors and piles in the ground.

In most works [2-7] Theoretical dependences for determining the torque of screwing screw anchors and piles into the ground are given. Data analysis shows that the magnitude of the torque is influenced by the geometrical parameters such as diameter and pitch of the rotor blades to the pile, as well as physical and mechanical characteristics of the soil.

One of the first national pile designs in which all the accumulated experience in the study of reducing the energy intensity of the screwing process was more fully implemented is screw piles, developed by specialists of JSC "Sevzapenergosetproekt" under the leadership of V. N. Zhelezkov. The design of the screw pile is a steel pipe with a welded blade with a diameter of 0.5 to 0.8 m, starting at the conical tip of the pile and passing to the cylindrical part [8-10]. The installation of the screw blade on the conical part reduces the amount of the necessary pressing force of the load that occurs when it is screwed in. The helical blade can be single-turn or double-turn, to increase the rigidity of the pile structure. This design is widely used because of its effectiveness in the construction of engineering structures in the military, as well as as the foundations of power transmission poles (figure 2.1). To reduce the required axial load and increase the load-bearing capacity, a screw pile can be made with two closely spaced blades, while their width should gradually increase [10].

Figure 2.1. Screw pile structures: left single-turn, right double-turn..

Figure 2.2. Krinner ground screws.

Krinner Ground Screws is a well-known design of screw piles in the form of a "screw", developed by specialists of the German company "KRINNER" [11]. They consist of a forged cone body and a pipe billet with a welded spiral (figure 2.2). The pile is protected from corrosion by hot-dip galvanizing in the factory.

Studies carried out by V. F. Akopyan [12,13] showed that during the construction of a screw pile in the form of a "screw", the surrounding soil is compacted, which contributes to an increase in its bearing capacity along the side surface. The disadvantages of this design include insufficient load-bearing capacity in weak clay soils. It is worth noting that these piles were originally developed for operation in conditions where there are no processes of frost heaving of soils.

One of the first designs of screw piles that appeared on the market of low-rise and cottage construction, as well as prefabricated temporary buildings, are piles created on the basis of effective structural solutions of large-diameter piles, in particular the design of Zhelezkov V. N. (Sevzapenergosetproekt) [14]. Piles have anti-corrosion coating, after the device piles internal cavity is usually filled with a concrete mixture to increase the durability of the structure, on top of the piles,
usually installed metal support element (the head), made of steel plate with holes on which you install the load bearing structures.

A distinctive feature of many screw pile designs used abroad [15-17] The main feature of the screw blade is that it is a single complete turn obtained from a sheet metal billet by laser cutting and then welding to the pile shaft. Obtaining a helical blade from a single billet, by separating the edges, in contrast to domestic designs, significantly simplifies the technological process of their manufacture (figure 2.3).

Piles can be made hollow, with a beveled end, and consist of separate standard sections (composite modular structures). Multi-blade piles (anchors) with a constant blade pitch are widely used. The blades can be of the same diameter (piles) or gradually decrease to the bottom of the pile, in the latter case they are more often used as anchors.

![Figure 2.3. Multi-blade screw piles.](image)

3. Practical application

3.1. Screw piles for block-modular buildings

Modular buildings made of blocks are becoming more and more popular, used as cabins, warehouses and even office premises for various purposes. They are distinguished by the speed of construction, since they are manufactured in stationary conditions of industrial enterprises and have the maximum degree of readiness.

Modules are structures consisting of a metal frame sheathed with profiled steel sheets. The sheets are protected by an anti-corrosion coating, insulated inside. In addition to compliance with the current regulations, the foundations are subject to increased requirements for the speed of work. The best option is to build a foundation using screw piles.

Pile foundations are made of screw piles during the construction of a block-modular building for military personnel for 250 people in Yoshkar-Ola (figure 3.1).

![Figure 3.1. Block-modular building.](image)

The diameter of the pile trunk is 108 mm. The thickness of the barrel wall is 4.0 mm, the diameter of the screw pile blade is 300 mm. The length of the screw pile is 3500 mm. The material of the screw
pile barrel is 3ps5 steel, the pile coating is Indosing1 EP. After sinking the screw pile, the inner cavity of the shaft was filled with M300 concrete mix.

Along the outer perimeter, the main binding is made of a metal profile pipe 100×50×3, material 3ps5 Steel (figure 3.2).

Figure 3.2. Piling of screw pile foundations.

Screw piles work well on the action of vertical, off-center and pulling loads.

The bearing capacity of a screw pile can be determined by calculation methods according to the formula given in clause 7.2.10 of Code of rules 24.13330.2011 "Pile foundations", by the method of static field tests according to clause 7.1.11, as well as by calculation using computer programs based on numerical modeling.

Geologically, the study area is represented by bulk deposits (tQIV) and clay deposits of the Tatar stage of the Upper Permian (P2t).

From the surface to a depth of 8.0 m, the geological and lithological structure is represented by the following consolidated engineering and geological section: soil-1 – fill soil, loamy, with the inclusion of construction waste; soil-2 – clay red, semi-solid (figure 3.3).

Figure 3.3. Geological section.

Figure 3.4. Static pile test results $S=f(P)$.

The bearing capacity $F_d$, kN, of a single-bladed screw pile with a blade diameter $d<1.2$ m and a length $l<10$ m, working on a pressing or anchor load, should be determined by the formula 7.15 CR 24.13330.2011:

$$F_d = \gamma_c [F_{d0} + F_{df}],$$

where $\gamma_c$ is the coefficient of the working conditions of the pile, depending on the type of load acting on the pile and ground conditions; $F_{d0}$ is the bearing capacity of the blade, kN; $F_{df}$ is the bearing capacity of the trunk, kN.

The bearing capacity of the screw pile blade is determined by the formula

$$F_{d0} = [\alpha_1 c_1 + \alpha_2 y_1 h_1]A,$$
where \( \alpha_1, \alpha_2 \) – dimensionless coefficients; \( c_1 \) – specific soil adhesion in the working area, kPa; \( \gamma_1 \) – the average value of the specific gravity of soils lying above the pile blade, kN/m\(^3\); \( h_1 \) – the depth of the pile blade from the natural terrain, m; \( A \) – the projection of the blade area, m\(^2\).

The bearing capacity of the screw pile shaft is determined by the formula

\[
F_{df} = uf_1(h - d),
\]

where \( u \) is the perimeter of the cross section of the pile shaft, m; \( f_1 \) – design resistance of the soil on the side of the screw pile shaft, kPa; \( h \) is the length of the pile shaft, sunk into the ground, m; \( d \) – diameter of the blade piles, m.

The modelling of the screw pile work in the ground using the Plaxis software package, taking into account the elastic-plastic work of the base (figure 3.4), was carried out. The bearing capacity of the screw pile according to the results of calculations by the finite element method is \( F_{df}=400 \) kN. The design load on the screw pile is \( N=49.2 \) kN. For a screw pile, consider the condition:

\[
\gamma_n \cdot N = 1.0 \cdot 492 (kN); \quad \frac{F_d}{Y_{c,g}} = \frac{400}{1.5} = 266.7 (kN). \quad \text{The condition is met: } \gamma_n \cdot N \leq \frac{F_d}{Y_{c,g}}.
\]

Thus, according to the results of calculations by the finite element method of the rules, the calculated load on the screw pile is \( \frac{F_d}{Y_{c,g}} = 266.7 \) (kN), and exceeds the design load on the pile by more than 5 times.

### 3.2. Construction of a warehouse in metal structures in the Republic of Mari El

Screw pile foundations were used during the construction warehouse for finished products of the glass factory in the Republic of Mari El. The sizes of the building in the plan are 198×18 (m×m). Experimental screw piles SHS-89/4500, SHS-133/4500 and SHS-159/4500 are made by screwing into the base using a gearbox and a hydraulic manipulator, followed by filling the pile cavity with concrete (figure 3.5). The diameter of the pile blade \( d \) is 250, 350 and 500 mm. Pile clusters are made of four screw piles with a metal grillage for supporting the frame column (figure 3.6).

In the geological structure of the site, modern technogenic \( t_{QIV} \) deposits are found, underlain by alluvial-fluvio-glacial deposits, represented by fine sands and hard-plastic clays (figure 3.7). To determine the load-bearing capacity, static pile tests of the soil were carried out at the experimental site (figure 3.8).

To determine the load-bearing capacity, static tests of the soil with piles were carried out at the experimental site. The tested piles were brought to a precipitation exceeding 3 cm – the maximum precipitation for buildings with a full metal frame.

As a result of the static tests of the piles, it was established:
- the load-bearing capacity of the pile with a diameter of \( d=250 \) mm was \( F_{p}=125 \) kN, the calculated load was respectively \( N=104.2 \) kN, the design load is 37.8 kN;
- the load-bearing capacity of the pile with a diameter of \( d=350 \) mm was \( F_{p}=165 \) kN, the calculated load was respectively \( N=137.5 \) kN, the design load is 63.7 kN;
- the load-bearing capacity of the pile with a diameter of \( d=500 \) mm was \( F_{p}=196 \) kN, the calculated load was respectively \( N=163 \) kN, the design load is 118.5 kN.
4. Numerical studies

The stress-strain state of the screw pile base is calculated in the Plaxis software package. The axisymmetric elastic-plastic task is solved, the size of the calculated area is 6×24 (m×m). The great importance has the question of load-bearing capacity of screw pile foundations. Calculations of the bases of screw piles on the action of pressing and anchor loads were performed for non-cohesive (fine sand, medium density) and cohesive soil (soft-plastic loam).

The influence of the blade diameter d and the length of the screw pile L on the stress state change in the basis is established. The characteristic graphs of the dependence of the settlements on the load are given (figure 4.1 to 4.4).

Figure 4.1, 4.2 shows the effect of d and L of a screw pile on load-bearing capacity and settlements (cohesive and non-cohesive soil). It was found that a change in the blade diameter d from 500 to 1200 mm at L=9 m leads to an increase in the load-bearing capacity of the pile for indentation loads by 2.5 times (cohesive soil) and by 2.9 times (non-cohesive soil).

An increase in the length of the screw pile L from 6 to 12 m at L=800 mm leads to an increase in the bearing capacity of the pile for indentation loads by 1.7 times (cohesive soil) and 1.6 times (non-cohesive soil).

Figure 4.3, 4.4 shows the results of calculations for the effect of pulling loads on a screw pile when changing d and L in cohesive and non-cohesive soils. It was found that a change in the blade diameter d from 500 to 1200 mm at L=9 m leads to an increase in the load-bearing capacity of the pile for pulling loads by 1.7 times (cohesive soil) and 1.7 times (non-cohesive soil).
Figure 4.1. Dependences of settlements from compression load $S=f(P)$ for crew pile in cohesive soil:
(a) $L=9$ m with different blade diameter $d$; (b) $d=800$ mm with different length $L$.

Figure 4.2. Dependences of settlements from compression load $S=f(P)$ for crew pile in non-cohesive soil:
(a) $L=9$ m with different blade diameter $d$; (b) $d=800$ mm with different length $L$.

Figure 4.3. Dependences of settlements from anchor load $S=f(P)$ for crew pile in cohesive soil:
(a) $L=9$ m with different blade diameter $d$; (b) $d=800$ mm with different length $L$.

Figure 4.4. Dependences of settlements from anchor load $S=f(P)$ for crew pile in non-cohesive soil:
(a) $L=9$ m with different blade diameter $d$; (b) $d=800$ mm with different length $L$. 
An increase in the length of the screw pile $L$ from 6 to 12 m at $L=800$ mm leads to an increase in the load-bearing capacity of the pile for pulling loads by 2.2 times (cohesive soil) and by 2.9 times (non-cohesive soil).

The analysis of changes in vertical displacements showed (figure 4.5(b)) that the isolines are elongated along the trunk of the screw pile, their concentration is noted at the pile, at a depth of $(2.0-2.5)\,d$ below the plane of the tip of the pile, the displacements account for 10-15% of the total precipitation.

Horizontal displacement isolines are closed (figure 4.5 (c)). The highest values of horizontal displacements are recorded in the area separated from the pile axis at a distance $(1.0-1.5)\,d$ below the plane of the tip and directed from the pile axis. This means that there is a compaction of the soil in this area.

The change in vertical stress $\sigma_y$ in the active zone with the self-weight of soil is illustrated by the contours in figure 4.5d. It is established that the maximum stress $\sigma_y$ occur in the plane of the pile toe and spread to a depth of $(1.5-2.0)\,d$.

**Figure 4.5.** Stress-strain state of the screw pile base under pressure loads: (a) is design scheme; (b), (c) is vertical and horizontal displacements; (d), (e) is vertical and tangential stresses; (f) is plastic points
The shear stresses $\tau_{xy}$ at the base are presented at the figure 4.5e, the highest values of shear stresses installed in the plane of the edge and reach values of 0.25 and 0.30 MPa.

The emergence and development of zones of the ultimate state of the soil has a significant impact on the redistribution of forces of the soil layer and the nature of the development of sediments (figure 4.5 (f)).

5. Conclusion
The use of nonlinear soil mechanics solutions allows us to assess the stress-strain state of the bases of screw piles in a large range of load changes up to the limit. Allows us to design the foundations according to the maximum permissible deformations.

References
[1] Glotov N M, Luga A A, Silin K S and Zavriev K S 1975 Pile foundations
[2] Bogorad L Y 1967 Screw piles and anchors in electric grid construction (Moscow)
[3] Kravtsov V N and Chebotar L S 2008 Efficiency of using screw piles in difficult ground conditions in Belarus Sci. Appl. Asp. Constr. Abovegr. Undergr. Struct. complex soils 186–91
[4] Lebedev S V 2012 Justification of the optimal parameters of the screw anchors and the rotation drive gearbox
[5] Penchuk V A 1985 Screw piles and anchors for supports
[6] Tsyuryupa I I 1958 Engineering structures on screw piles
[7] Zhelezkov V N 2004 Screw piles in the energy and other construction industries
[8] Anon 1988 Standard structures, products and components of buildings and structures. Series 3.407.9-158. Unified structures for fixing the supports of overhead lines and substation OPUS. Issue 2. Screw anchors and piles. KM stage
[9] Zhelezkov V N 2009 Modern designs of screw piles and anchors Constr. Mach. Equip. 22
[10] Zhelezkov V N 2008 Large and small diameter screw piles
[11] Official cite of Krinner company. www.krinner.com.
[12] Akopyan V F 2010 Modeling the load-bearing capacity of screwed piles Proc. Rostov State Univ. Civ. Eng. 14 p 308
[13] Akopyan V F 2012 Simulation of the joint operation of screw piles with a non-linearly deformable ground base
[14] Ponomarenko Y Y 2013 Features of regulatory documentation in the design of foundations made of screw anchors and piles Soils Found. 1 28–31
[15] A.B. Chance Company 1994 Chance Anchor Corrosion Report Bulletin 31-9403 (Texas Dept. of Transportation, Copyright, Centralia, MO)
[16] Official cite of Almita Piling Inc. http://www.almita.com/installation
[17] Official cite of Magnum company. http://www.magnumpiering.com