DOI:10.22337/2587-9618-2025-21-1-222-232

DESIGN OF FOUNDATION STRENGTHENING WITH PILES FOR THE RECONSTRUCTION OF BUILDINGS ON CLAY SOILS

***Anatoly I. Polishchuk* [1], *Arkady A. Petukhov* [1], *Nadezhda S. Nikitina* [2], *Ivan V. Semenov* [1]**

[1] Kuban State Agrarian University named after I.T. Trubilin. Krasnodar, RUSSIA
[2] National Research Moscow State University of Civil Engineering, Moscow, RUSSIA

Abstract. The paper presents the main stages of designing the strengthening of shallow foundations with piles made in clay soil (injection and bored-injection) for reconstructed buildings. Such foundations are often called combined foundations. The basic methods for installing these piles as part of reinforced foundations are presented, including injection cylindrical piles, bored-injection cylindrical piles of Titan and Atlant types, and bored-injection conical piles. The methodology of foundation strengthening design with the use of such piles is discussed. As a result of investigations of soil properties, lithologic structure of the base and other parameters the procedure of evaluation of soil conditions of construction sites is shown. The data on assessment of technical condition of bases and foundations of reconstructed buildings are presented. The article presents the main results of tests of injection piles, provides guidelines for determining their load-bearing capacity. It provides information on verification calculations performed while designing foundations reinforced by injection (bored-injection) piles, including the determination of the design resistance of the compacted soil of the base. An engineering method for calculating the settlement of reinforced foundations with injected, bored-injected piles in clay soils, which can be used in the design practice of reconstructed buildings, has been presented. The method allows accounting for the displacement (settlement) of the soil due to its weakening in the places of wells for the piles and data on the change in the stress state of the base under the bottom of the slab part of the foundation.

Keywords: strengthened foundation, injection and bored-injection piles, reconstruction of buildings, assessment of soil conditions of construction, foundation strengthening solutions

ПРОЕКТИРОВАНИЕ УСИЛЕНИЯ ФУНДАМЕНТОВ С ИСПОЛЬЗОВАНИЕМ СВАЙ ПРИ РЕКОНСТРУКЦИИ ЗДАНИЙ В ГЛИНИСТЫХ ГРУНТАХ

***А.И. Полищук* [1], *А.А. Петухов* [1], *Н.С. Никитина* [2], *И.В. Семёнов* [1]**

[1] Кубанский государственный аграрный университет им. И. Т. Трубилина, г. Краснодар, РОССИЯ
[2] Национальный исследовательский Московский государственный строительный университет, г. Москва, РОССИЯ

Аннотация. Приведены основные этапы проектирования усиления фундаментов мелкого заложения сваями, изготавливаемыми в глинистом грунте (инъекционные и буроинъекционные) для реконструируемых зданий. Такие фундаменты часто называют комбинированными. Представлены основные способы устройства указанных выше свай в составе усиливаемых фундаментов, включая инъекционные цилиндрические сваи, буроинъекционные цилиндрические сваи конструкции «*Titan*», «*Атлант*», буроинъекционные конические сваи. Дана методика проектирования усиления фундаментов с использованием таких свай. По результатам исследований свойств грунтов, литологического строения основания и других параметров показан порядок выполнения оценки грунтовых условий площадок строительства. Представлены данные по оценке технического состояния оснований и фундаментов реконструируемых зданий. Приведены основные результаты испытаний инъекционных свай, даны указания по определению их несущей способности. Приведены сведения о поверочных расчетах, выполняемых при проектировании фундаментов, усиливаемых инъекционными, буроинъекционными сваями, в том числе по определению расчетного сопротивления уплотненного грунта основания. Представлен инженерный метод расчета осадок усиливаемых фундаментов с инъекционными, буроинъекционными сваями в глинистых грунтах, который может использоваться в проектной практике реконструируемых зданий. Метод позволяет учитывать перемещения (осадки) грунта за счет его ослабления в местах устройства скважин под рассматриваемые сваи и данные об изменении напряженного состояния основания под подошвой плитной части фундамента.

Ключевые слова: усиливаемый фундамент, инъекционные и буроинъекционные сваи, реконструкция зданий, оценка грунтовых условий строительства, решения по усилению фундаментов

BASIC PROVISIONS

A way to increase the load-bearing capacity of shallow foundations is to change the scheme of operation by transferring part of the load from the building to the piles. The foundation thus formed is often called a combined foundation. In this case, the piles can be arranged under the footing of the foundation through its slab part or adjacent to its perimeter (Fig. 1).

In recent years, injection and bored-injection piles have been increasingly used to strengthen the foundations of reconstructed buildings. Injection piles are defined as structures that are formed in prepared (ready-made) boreholes by injecting into them under pressure a mixture of fine-grained concrete with subsequent pressure testing of the system “pile - base soil” (Polischuk A.I., Petukhov A.A. et al., 2003). In the case of such piles, the borehole is constructed by preliminary pushing into the ground steel tubular injectors of special design (Fig. 2) [1, 2, 3]. If the borehole is drilled using auger or other equipment such piles are usually called Titan cylindrical bored injection piles [4, 5]. [4, 5]. They were introduced in construction by Ishebek (Germany, 1956). The considered bored-injection cylindrical piles are used mainly for the action of vertical compressive and pulling (anchor) loads. Sometimes they are called Titan bored-injection anchor piles (Fig.3). In Russia, the Titan piles have been used since about 1985-1990. As a development of Titan bored-injection piles, the company InzhProektStroy (Russia) in 2006-2008 proposed a design solution of Atlant bored-injection piles for compressive and pull-out (anchor) loads, as well as for moment forces (Fig. 4).

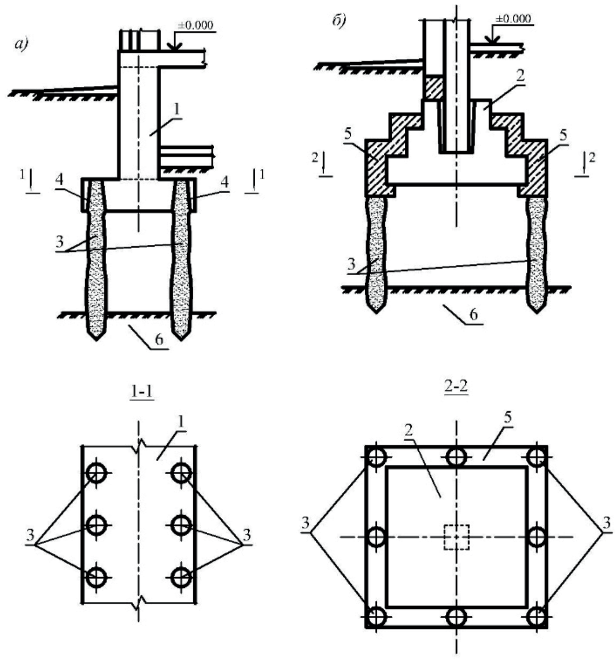
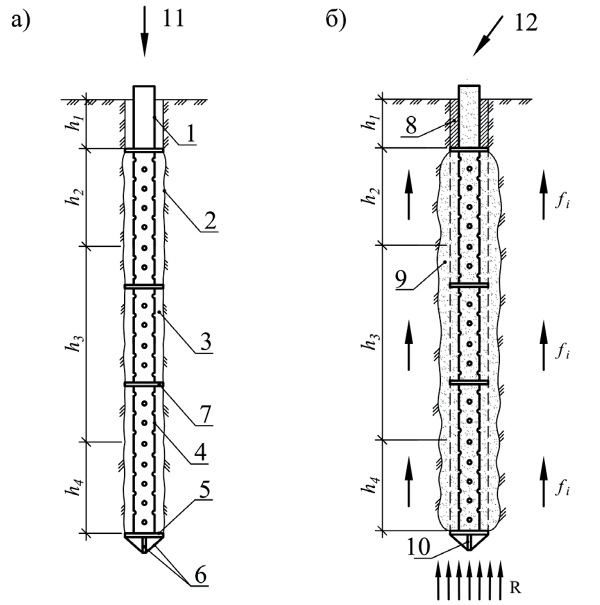
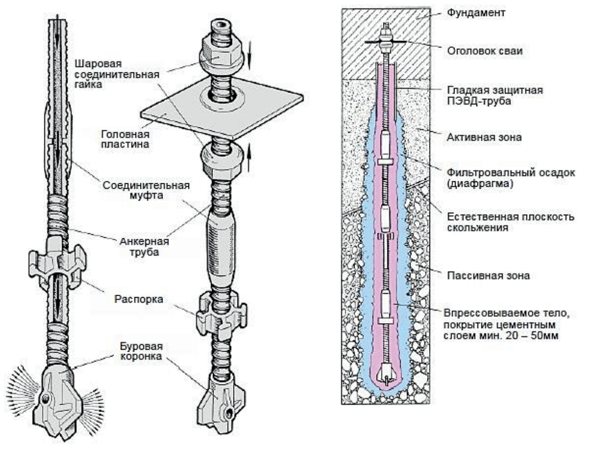


Figure 1. Foundations reinforced by injection (bored-injection) piles: a - under the bottom of the existing strip foundation; b - adjacent to the slab part of the existing separate foundation; 1 - existing strip foundation; 2 - existing separate foundation; 3 - injection (bored-injection) piles; 4 - cone hole in the slab part of the foundation; 5 - reinforced concrete cage; 6 - bearing layer of the foundation soil

As part of the development of design solutions for bored-injection cylindrical piles, D.A. Chernyavskiy, O.Y. Yeschenko (2010), and later G.G. Solonov, D.A. Chernyavskiy et al. (2024) proposed a device and a method for manufacturing bored-injection conical piles, which are now increasingly used in new construction and building reconstruction (Fig. 5) [6, 24].

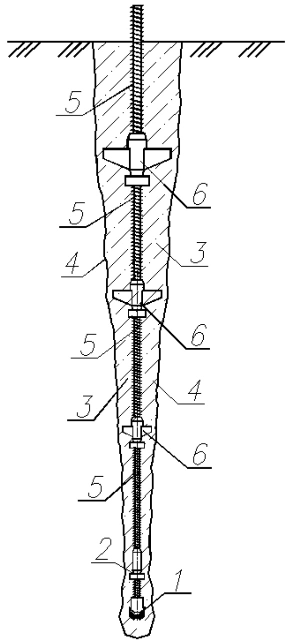


<u>Figure 2.</u> Injection piles and schemes of their formation in the soil (authors A.I. Polishchuk, A.A. Petukhov et al.).: a - Injector immersion; b - Arrangement of injection pile by injecting fine-grained concrete; 1 - Injector section without perforation; 2 - Well side surface; 3 - Air gap between injector and well wall; 4 - Injector section with perforation; 5 - Injector pipe widening at the bottom of the injection pile for air gap arrangement; 6 - Cutting plates; 7 - injection pipe widening along the injection pile; 8 - well plugging; 9 - expandable part of the injection pile during concrete mixture injection; 10 - lower end of the pile; 11 - injector push-in force; 12 - direction of concrete mixture injection



<u>Figure 3</u>. Structural elements of Titan cylindrical (anchor) bored injection pile (Germany)

<u>Figure 4.</u> General view of constituent structural elements of the Atlant bored-injection pile (Russia)



<u>Figure 5.</u> Scheme of bored-injection conical pile (authors D.A. Chernyavskiy, O.Y. Yeschenko): 1 - drill bit; 2 - connecting coupling; 3 - fine-grained concrete mixture; 4 - lateral surface of the borehole; 5 - hollow steel rod; 6 - drill bit with drilling blades

METHODOLOGY FOR FOUNDATION STRENGTHENING DESIGN AND PILE PERFORMANCE STUDIES

The design methodology for strengthening of shallow foundations of reconstructed buildings includes the following stages: selection of experimental sites for testing of full-scale injection (bored-injection) piles; performance of engineering and geological surveys; manufacturing of structural elements of piles; preparation of fine-grained concrete mixture and its experimental injection into boreholes; construction of injection, bored-injection piles at the selected site; investigation of physical and mechanical properties of soils in the pile space; testing of injection (bored-injection) piles by static indentation load. The experience of the above methodology can be borrowed from the authors' publications and technical literature [1, 7, 8, 9] for the period from 2003-2023.

For example, experimental studies at the experimental sites in Tomsk and Kemerovo were grouped into series of experiments [1, 10]. Injection piles with lengths of 1.5, 3.5, 5.0 m without widening injectors and with extensions at the level of their lower ends in the form of tips to form an air gap were applied (Fig. 6). Each injector pipe had two sections: a "blind" section, usually up to 1.5 m long, and a section with 15-20 mm diameter holes staggered at 80-100 mm spacing. At the boundary between these sections, a ring of the same diameter as the tip widening was provided.

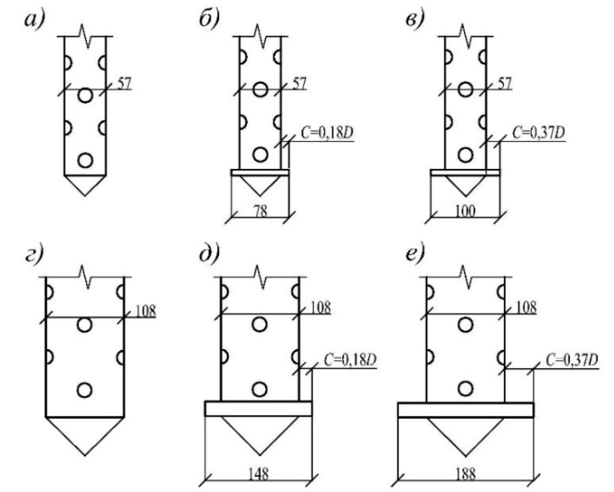


Figure 6. Design solution of tips for 57 mm (a, b, c) and 108 mm (d, e, f) diameter injectors used in the production of injection piles: a, d - tips for piles without widening; b, e - the same with widening diameter (1.37-1.4)D; c, f - the same with widening diameter (1.75-1.8)D, where D is the injector diameter

Injectors were immersed up to the design level using a hydraulic long-rod jack due to the cramped conditions at the experimental site in Tomsk and a drilling rig UGB-1BC at the experimental site in Kemerovo. Injection of fine-grained concrete was carried out with the help of a CO-49 m and CO-180 pump, providing a constant rate of its supply of about 2.5 m^3/h. The maximum pressure created by the pump was 1.5-2.0 MPa. The concrete mixture was injected into the boreholes in portions of 0.1 m^3 with technological breaks for 5-10 min for "intermediate" pressing of the soil mass with working pressure (Fig. 7). The concrete mixture was injected up to the specified volume calculated on the basis of the geometry of the piles being constructed. After injection of the concrete mixture, the soil in the pile space was pressurized by maintaining the working pressure in the borehole for a specified period of time to ensure soil compaction around the pile shaft.

KEY RESULTS AND THEIR ANALYSIS

Results of assessment of soil properties and soil conditions of construction. The evaluation of base soils enables designers to choose the most rational solution for the reconstruction of buildings in terms of their reliability and cost-effectiveness [1, 11]. Studies of changes in physical and mechanical properties of soils around the shaft of injection piles were carried out on the selected soil monoliths from pilot sites (Kemerovo, Tomsk). The change of soil density ρ in the surrounding massif along the length of the pile was revealed. In the natural state, the soil density (ρ) was 1.70-1.73 g/cm^3, while at the boundary of the pile shaft with the soil mass the soil density changed and reached 1.97-1.98 g/cm^3.

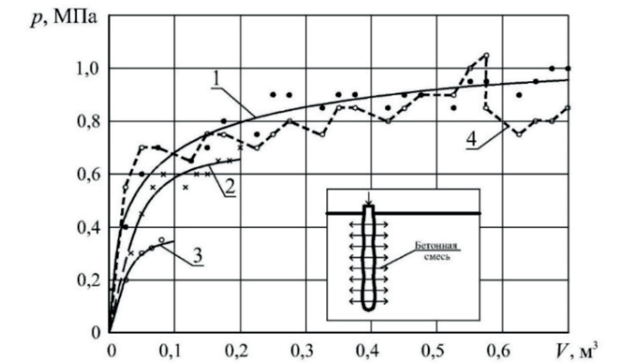


Figure 7. Changes in injection pressure p (MPa) of the concrete mixture for injection piles: 1 - 5.0 m long piles (site 1); 2 - 3.5 m long piles (site 1); 3 - 1.5 m long piles (site 2); 4 - 5.0 m long piles (site 1 - with soil fracturing)

The specific cohesion of the clayey soil after pile placement increased from 13.3-15.0 kPa to 18.2-18.6 kPa within a distance of up to 500 mm from the lateral surface of the piles. At the same time, the angle of internal friction of clayey soil increased insignificantly, by 1-3 deg [1, 9, 10]. According to the results of static soil probing, it was found that after pile arrangement the soil resistance under the probe tip within the length of the arranged pile q_c increased 1.5-2.0 times and amounted to 1.5-2.2 MPa. Soil resistance on the lateral surface of the probe f_s. within the depth of the pile increased by 1.4-1.5 times. Based on the results of studies of soil properties, lithologic structure of the foundation and other parameters, the soil conditions of the test sites under consideration were evaluated [20, 22].

Assessment of the technical condition of foundations. For reconstructed buildings, the condition of foundations shall be established based on the results of inspection, including the examination of the base soils and verification calculations [1, 12]. Based on the results of the work performed, considering the identified defects, damages and verification calculations, their technical condition can be assessed in accordance with the requirements of GOST 31937-2011 and other technical literature [13, 14].

Since 2011 there have been 4 groups for assessing the category of technical condition of building structures, including base soils, according to GOST 31937-2011 in Russia. According to this standard, load-bearing building structures and foundation soils may be in: normative technical condition, serviceable condition, limited serviceable condition and emergency condition.

Test results of injection piles and justification of their bearing capacity. Tests of injection piles were carried out in accordance with GOST 5686-2020. Analysis of the results of injection pile tests allowed to reveal the nature of their operation performance under load. For example, in the considered tests at pilot sites (Kemerovo, Tomsk) it was found that for injection piles with injectors without tips (Fig. 6) the bearing capacity F_d was the lowest. For piles having injectors with bottom end extensions in clayey soils their bearing capacity F_d increases. Significant increase of up to 20-30 % and more in the bearing capacity F_d of injection piles was detected if the diameter of the widening D_y exceeded the injector diameter D by a distance C = (0.37-0.4)D.

To substantiate the bearing capacity of injection piles, the requirements of regulatory documents and technical literature (SP 24.13330.2021; Mangushev R.A. et al., 2015; Handbook of Geotechnical Engineering, 2023; Polishchuk A.I. et al., 2023) have been utilized. The value of external load $N = F_d$, which corresponded to their settlement equal to 10 mm, was taken as the bearing capacity F_d of injection piles at the pilot sites in the cities of Kemerovo and Tomsk [1]. In the absence of data on in-situ tests of piles, their bearing capacity can be determined using formulas and methods presented in regulatory and technical documentation and publications of authors [2, 9, 14, 15, 16, etc.].

Loading assessment of strengthened foundations. Loading assessment of strengthened (combined) foundations means the analysis of initial data and calculation results, which reveals the compliance of their design solution with the current loads (N, M, Q) and ground conditions of the construction site of the building being reconstructed [17, 18]. During the loading assessment, verification calculations are first performed for shallow foundations before they are strengthened (before the building is reconstructed). In particular, the design resistance of the compacted base soil R_{up} must be determined and compared with the pressure at the bottom of the shallow foundations p ($p \leq R_{up}$) before and after reconstruction [22]. In addition, the foundation settlement S and its irregularity ΔS are also determined. If the pressure p exceeds the design resistance R_{up} ($p > R_{up}$) or the settlement S or the irregularity of settlement ΔS of the foundations exceeds the permissible limits, the foundation should be strengthened with piles ("strengthened foundation") [9, 19]. The strengthened foundation is then designed [7, 14, 22].

Verification calculations of the final settlement of the foundation S strengthened by injection (bored-injection) piles should be performed according to the requirements of SP 22.13330.2016. The engineering calculation method developed by the authors can also be utilized, according to which the foundation settlement S_{req} (mm) of the reconstructed building is determined considering the nonlinear relationship between stresses and deformations in the soil [2, 21, 23] using the formula:

$$S_{rec} = S_o \cdot k_n + S_f(k_{tech} - 1), \qquad (1)$$

where S_o is the final settlement of single injection piles (injection pile), mm [19, 20]; S_f is the design settlement of the existing shallow foundation (before strengthening with piles), determined by calculation mm; $k_{tech} = 1.01 - 1.13$ is the coefficient, which takes into account soil displacement (settlement) due to soil shrinkage along the borehole walls during injection pile installation; k_n = 0.93–0.98 – coefficient, which takes into account the data on the change in the stress state of the soil in the basement under the bottom of the slab part of the foundation after the installation of injection piles.

Thus, the proposed sequence of actions in the design of foundation reinforcement with the use of piles (injection, bored-injection) allows to properly organize the main stages of work of specialists and create an effective design solution that ensures its reliable operation for reconstructed buildings in clay soils.

CONCLUSIONS

1. The paper provides data on the performance of reinforced concrete foundations formed from shallow foundations when their slab part is reinforced with injection or bored-injection piles of 3...8 m length. The scope of application of the considered structural solutions of foundations extends mainly to reconstructed buildings in clay soils, including weak soils.
2. It has been found that injection and bored-injection piles made of fine-grained concrete are now increasingly used for strengthening foundations of reconstructed buildings. In particular, the introduction of injection piles was carried out at the objects of reconstructed buildings in Tomsk and Kemerovo (2005-2008), and bored-injection piles at the objects in Sochi and Krasnodar (2020).
3. The proposed engineering method for calculating settlements of foundations strengthened by injection, bored-injection piles in clayey soils can be used for the conditions of building reconstruction. The method allows to account for the displacement (settlement) of the soil from the external load at the locations of wells and data on the change in the stress state of the foundation soil under the bottom of the slab part of the foundation.

REFERENCES

1. **Polishchuk A.I., Petuhov A.A., Semyonov I.V.** Usilenie fundamentov in"ekcionnymi svayami pri rekonstrukcii zdanij [Strengthening foundations with injection piles during reconstruction of buildings] 2-nd edition, added. M.: Publishing house ASV, 2023. 212 р. м
2. **Polishchuk A.I., Semyonov I.V.** Raschet osadki kombinirovannogo fundamenta dlya rekonstruiruemogo zdaniya v glinistyh gruntah [Calculation of the settlement of a combined foundation for a reconstructed building in clay soils] *Osnovaniya, fundamenty i mekhanika gruntov*. 2022, No 6, pp.7-11.
3. **Polishchuk A.I., Gerasimov O.V., Petukhov A.A., Andriyenko YU.B., Nuykin S.S.** Sposob ustroystva in"yektsionnoy svai [Method for the device of injection piles]. Patent Rossiiskaia Federatsiia no. 2238366 (2014).

4. **Bruce, D.A., Bruce, M.E.C., and Traylor, R.P.** (1999). «High Capacity Mi-cropiles – Basic Principals and Case Histories» GeoEngineering for Underground Facilities.Proc. of the 3rd National Conference of the Geo-Institute of the American Society of Civil Engineers. Geotechnical Special Publication No. 90, Urbana-Champaign, IL, June 13-17, pp. 188-199.
5. **Jeon, S., and Kulhawy, F.H.** (2002). «Evaluation of axial compression be-havior of micropiles» Proceeding of a Specialty Conference – Foundation and ground improvement, Blacksburg VI, ASCE, pp. 460-471.
6. **CHernyavskij D.A.** Ocenka vliyaniya prochnostnyh harakteristik glinistyh gruntov na nesushchuyu sposobnost' odinochnyh konicheskih buroin"ekcionnyh svaj [Assessment of the influence of the strength characteristics of clay soils on the bearing capacity of single conical drilled injection piles] *Vestnik PNIPU. Stroitel'stvo i arhitektura,* 2018, No 4, pp.69-79. DOI: 10.15593/2224-9826/2018.4.07.
7. **Mangushev R.A., Gotman A.L., Znamenskij V.V., Ponomarev A.B**. Svai i svajnye fundamenty. Konstrukcii, proektirovanie i tekhnologii [Piles and pile foundations. Structures, design and technology] M.: Publishing house ASV, 2018, 320 p.
8. **Tarasov A.A.** Razvitiye metodov raschota in"yektsionnykh svay v slabykh glinistykh gruntakh dlya fundamentov rekonstruiruyemykh zdaniy [Development of methods for calculating injection piles in weak clay soils for the foundations of reconstructed buildings]: avtoref. dis. … cand. tech. sc. Tomsk, 2015, 23 p.
9. Directory geotechnics. Bases, foundations and underground structures. 3rd ed. Eds. V.A. Ilichev, R.A. Mangushev. Moscow, ASV, 2023, 1084 p.
10. **Petuhov A.A.** Sovershenstvovanie sposoba ustrojstva in"ekcionnyh svaj v slabyh glinistyh gruntah dlya uslovij rekonstrukcii zdanij [Improving the method of installing injection piles in weak clay soils for building reconstruction conditions]: avtoref. dis. … cand. tech. sc. Tomsk, 2006, 23 p.
11. **Zakharov M.S., Mangushev R.A.** Inzhenerno-geologicheskiye i inzhenerno-geotekhnicheskiye izyskaniya v stroitel'stve [Engineering-geological and engineering-geotechnical surveys in construction] Edited by R. A. Mangushev. Moscow, Saint-Peterburg : Publishing ASV, 2014, 176 p.
12. **Zemlianskii A.A**. Obsledovanie i ispytanie zdanii i sooruzhenii [Inspection and testing of buildings and structures] M.: Publishing house ASV, 2002, 240 p.
13. **Plevkov V.S., Mal'ganov A.I., Baldin I.V.** Otsenka tekhnicheskogo sostoyaniya, vosstanovleniye i usileniye stroitel'nykh konstruktsiy inzhenernykh sooruzheniy: uchebnoye posobiye [Assessment of the technical condition, restoration and strengthening of building structures of engineering structures] / Edited by V. S. Plevkov. 2-nd edition, remastered and added. Moscow: Publishing ASV, 2014, 328 p.
14. **Polishchuk A.I., Semyonov I.V., Demchenko V.A.** Main reasons for strengthening foundations and base soil stabilizations of used buildings. *Journal of Physics: Conference Series : 2*, Perm, 26–28 may 2021. Perm, 2021. P. 012029. – DOI 10.1088/1742-6596/1928/1/012029. – EDN QJREFB.
15. **Gotman A.L.** Svai i svaynyye fundamenty. Izbrannyye Trudy [Piles and pile foundations. Selected works: monograph] Ufa : IDPO UGNTU, 2015, 384 p.
16. **Pronozin, YA.A., Samokhvalov M.A.** Raschet vzaimodeystviya buroin"yektsionnykh svay s gruntovym osnovaniyem [Calculation of the interaction of bore-injection piles with a soil foundation] *Osnovaniya, fundamenty i mekhanika gruntov*. 2018, No 2, pp. 14-17.
17. **Filippovich A.A.** Vzaimodejstvie lentochnyh fundamentov rekonstruiruemyh zdanij s glinistym gruntom osnovaniya pri ih usilenii in"ekcionnymi svayami [Interaction of strip foundations of reconstructed buildings with clay foundation soil when

they are reinforced with injection piles]: avtoref. dis. … cand. tech. sc. Volgograd, 2014, 23 p.
18. **Konovalov P.A., Konovalov V.P.** Osnovaniya i fundamenty rekonstruiruemyh zdanij [Foundations and foundations of reconstructed buildings] M.: Publishing house ASV, 2011, 384 p.
19. **Polishchuk A.I.** Razrabotka metoda rascheta osadki odinochnoj in"ekcionnoj svai v glinistyh gruntah [Development of a method for calculating the settlement of a single injection pile in clayey soils]. *IV Mezhdunarodnaya nauchno-prakticheskaya molodezhnaya konferenciya po geotekhnike : sbornik materialov, Tyumen'*, 28–30 September 2018. Tyumen', Tyumen Industrial University, 2018, pp. 67-69. – EDN XZPKYP
20. **Polishchuk A.I., Nikitina N.S., Petukhov A.A., Semyonov I.V.** Strengthening of the Foundations of Renovated Buildings With Injection Piles. *International Journal for Computational Civil and Structural Engineering.* 2021, Vol. 17, No. 1, pp. 75-86. DOI 10.22337/2587-9618-2021-17-1-75-86. – EDN RCSPAE.
21. **Malyshev M.V., Nikitina N.S.** Raschet osadok fundamentov pri nelinejnoj zavisimosti mezhdu napryazheniyami i deformaciyami v gruntah [Calculation of foundation settlements with a nonlinear relationship between stresses and deformations in soils] *Osnovaniya, fundamenty i mekhanika gruntov*. 1982, No 2, pp.21-24.
22. **Nikitina N.S., Kravchenko D.A., Remizova N.V.** Sravnitel'nyj analiz metodov vozvedeniya fundamentov na prosadochnyh gruntah [Comparative analysis of methods for constructing foundations on subsidence soils] *Vestnik MGSU*. 2025, Vol. 20, No 3.
23. **Polishchuk A.I., Marinichev M.B.** Osnovaniya i fundamenty, podzemnye sooruzheniya [Foundations and bases, underground structures] Krasnodar, Kuban State Agrarian University, 2024. 612 p.
24. **Maksimov F.A.** Sovershenstvovanie konstrukcii i metodov rascheta vintovyh dvuhlopastnyh svaj v glinistyh gruntah [Improving the design and calculation methods of screw two-blade piles in clay soils]: avtoref. dis. … cand. tech. sc. Volgograd, 2018, 24 p.
25. **Polishchuk A.I., CHernyavskij D.A., Solonov G.G.** Osobennosti ustrojstva buroin"ekcionnyh konicheskih svaj v glinistyh gruntah [Features of the device of bored conical piles in clay soils]. *Sbornik statej po materialam konferencii, posvyashchennoj 50-letiyu arhitekturno-stroitel'nogo fakul'teta, posvyashchennoj 50-letiyu arhitekturno-stroitel'nogo fakul'teta*, 28 March 2024. Krasnodar, Kuban State Agrarian University, 2024, pp. 97-101. – EDN DUYBFA

СПИСОК ЛИТЕРАТУРА

1. **Полищук А.И.** Усиление фундаментов инъекционными сваями при реконструкции зданий: монография / А. И. Полищук, А. А. Петухов, И. В. Семёнов; под ред. д-ра техн. наук, профессора А. И. Полищука / 2-е изд., доп. – М.: Изд-во АСВ, 2023. – 212 с.
2. **Полищук А.И.** Расчет осадки комбинированного фундамента для реконструируемого здания в глинистых грунтах / А. И. Полищук, И. В. Семёнов // Основания, фундаменты и механика грунтов. – 2022. – №6. – С.7-11.
3. Пат. 2238366. Российская Федерация, МПК E 02 D 5/34. Способ устройства инъекционной сваи / Полищук А.И., Герасимов О.В., Петухов А.А., Андриенко Ю.Б., Нуйкин С.С. ; заявитель и патентообладатель ЗАО «Научно-производственное объединение «Георeконструкция»» - № 2003106150/03; заявл. 04.03.2003; опубл. 20.10.2004, Бюл. № 29. – 10 с.
4. **Bruce, D.A., Bruce, M.E.C., and Traylor, R.P.** (1999). «High Capacity Mi-cropiles – Basic Principals and Case Histories» GeoEngineering for Underground Facilities.Proc. of the 3rd National Conference

of the Geo-Institute of the American Society of Civil Engineers. Geotechnical Special Publication No. 90, Urbana-Champaign, IL, June 13-17, pp. 188-199.
5. **Jeon, S., and Kulhawy, F.H**. (2002). «Evaluation of axial compression be-havior of micropiles» Proceeding of a Specialty Conference – Foundation and ground improvement, Blacksburg VI, ASCE, 460-471.
6. **Чернявский Д.А.** Оценка влияния прочностных характеристик глинистых грунтов на несущую способность одиночных конических буроинъекционных свай / Д. А. Чернявский // Вестник ПНИПУ. Строительство и архитектура. – 2018. – Т. 9, № 4. – с. 69–79. – DOI: 10.15593/2224-9826/2018.4.07.
7. **Мангушев Р.А.** Сваи и свайные фундаменты. Конструкции, проектирование и технологии / Р. А. Мангушев, А. Л. Готман, В. В. Знаменский, А. Б. Пономарев. – М.: Изд-во АСВ, 2018. – 320 с.
8. **Тарасов А.А.** Развитие методов расчёта инъекционных свай в слабых глинистых грунтах для фундаментов реконструируемых зданий: автореф. дис. … канд. техн. наук. – Томск, 2015. – 23 с.
9. Справочник геотехника. Основания, фундаменты и подземные сооружения: 3-е издание, дополненное и переработанное / Под общ. ред. В.А. Ильичева и Р.А. Мангушева. – М.: Изд-во АСВ, 2023. С.1084.
10. **Петухов А.А.** Совершенствование способа устройства инъекционных свай в слабых глинистых грунтах для условий реконструкции зданий: автореф. дис. … канд. техн. наук. – Томск, 2006. – 23 с.
11. **Захаров М.С**. Инженерно-геологические и инженерно-геотехнические изыскания в строительстве : учеб. пособие / М. С. Захаров, Р. А. Мангушев; под ред. Р. А. Мангушева. – М., СПб. : Изд-во АСВ, 2014. – 176 с.
12. **Землянский А.А**. Обследование и испытание зданий и сооружений / А.А. Землянский. – М.: Изд-во АСВ, 2002. – 240 с.
13. **Плевков В. С., Мальганов А.И., Балдин И.В.** Оценка технического состояния, восстановление и усиление строительных конструкций инженерных сооружений: учебное пособие / Под ред. В. С. Плевкова. 2-е изд. перераб. и доп. – М.: Изд-во АСВ, 2014. – 328 с.
14. **Polishchuk, A.I.** Main reasons for strengthening foundations and base soil stabilizations of used buildings / A.I. Polishchuk, I.V. Semyonov, V.A. Demchenko // Journal of Physics: Conference Series : 2, Perm, 26–28 мая 2021 года. – Perm, 2021. – P. 012029. – DOI 10.1088/1742-6596/1928/1/012029. – EDN QJREFB.
15. **Готман А.Л.** Сваи и свайные фундаменты. – Уфа: ИДПО УГНТУ, 2015. – 384 с.
16. **Пронозин Я.А.** Расчет взаимодействия буроинъекционных свай с грунтовым основанием / Я. А. Пронозин, М. А. Самохвалов // Основания, фундаменты и механика грунтов. – 2018. – № 2. – С. 14-17.
17. **Филиппович А.А.** Взаимодействие ленточных фундаментов реконструируемых зданий с глинистым грунтом основания при их усилении инъекционными сваями: автореф. дис. … канд. техн. наук. – Волгоград, 2014. – 23 с.
18. **Коновалов П. А.** Основания и фундаменты реконструируемых зданий / П. А. Коновалов, В. П. Коновалов. – 5-е изд. перераб. и доп. – М.: Изд-во АСВ, 2011. – 384 с.
19. **Полищук А.И.** Разработка метода расчета осадки одиночной инъекционной сваи в глинистых грунтах / А. И. Полищук, И. В. Семенов // IV Международная научно-практическая молодежная конференция по геотехнике : сборник материалов, Тюмень, 28–30 сентября 2018 года / Тюменский индустриальный университет. – Тюмень: Тюменский индустриальный университет, 2018. – С. 67-69. – EDN XZPKYP.

20. Strengthening of the Foundations of Renovated Buildings With Injection Piles / A. I. Polishchuk, N. S. Nikitina, A. A. Petukhov, I. V. Semyonov // International Journal for Computational Civil and Structural Engineering. – 2021. – Vol. 17, No. 1. – P. 75-86. – DOI 10.22337/2587-9618-2021-17-1-75-86. – EDN RCSPAE.
21. **Малышев М.В., Никитина Н.С.** Расчет осадок фундаментов при нелинейной зависимости между напряжениями и деформациями в грунтах / М.В. Малышев, Н.С. Никитина // Основания, фундаменты и механика грунтов. – 1982. – №2. – С.21–24.
22. **Никитина Н.С., Кравченко Д.А., Ремизова Н.В.** Сравнительный анализ методов возведения фундаментов на просадочных грунтах / Н.С. Никитина, Д.А. Кравченко, Н.В. Ремизова // Вестник МГСУ. 2025 Том 20, № 3.
23. **Полищук, А.И**. Основания и фундаменты, подземные сооружения : учебник / А. И. Полищук, М. Б. Мариничев. – Краснодар : Кубанский государственный аграрный университет, 2024. – 612 с. – EDN TQRMTU.
24. **Максимов, Ф.А.** Совершенствование конструкции и методов расчета винтовых двухлопастных свай в глинистых грунтах [Текст]: автореф. дис. … канд. техн. наук. – Волгоград, 2018. – 24 с.
25. **Полищук, А. И.** Особенности устройства буроинъекционных конических свай в глинистых грунтах / А. И. Полищук, Д. А. Чернявский, Г. Г. Солонов // Современные векторы развития архитектуры и строительства : Сборник статей по материалам конференции, посвященной 50-летию архитектурно-строительного факультета, посвященной 50-летию архитектурно-строительного факультета, Краснодар, 28 марта 2024 года. – Краснодар: Кубанский государственный аграрный университет им. И.Т. Трубилина, 2024. – С. 97-101. – EDN DUYBFA.

Anatoly I. Polishchuk, Professor at the Department of Bases and Foundations, Kuban State Agrarian University named after I.T. Trubilin (Krasnodar), Honored Builder of the Russian Federation, Honorary Worker of Higher Professional Education of the Russian Federation, holder of the Honorary Diploma of the President of the Russian Federation, Doctor of Technical Sciences, Professor. Specialist in the field of foundation construction, building inspection and reconstruction. Member of the Presidium of the Russian Society for Soil Mechanics, Geotechnics and Foundation Construction, holder of the N.M. Gersevanov Medal. Author, co-author of 8 monographs, 2 regional normative documents, 18 educational and scientific-practical manuals, 3 reference books, 40 patents of the Russian Federation for inventions, in total more than 260 scientific printed works. (Russia, 350044, Krasnodar, 13, Kalinina str., E-mail: ofpai@mail.ru).

Полищук Анатолий Иванович, Профессор кафедры «Основания и фундаменты» Кубанского государственного аграрного университета им. И. Т. Трубилина (г. Краснодар), заслуженный строитель РФ, почетный работник высшего профессионального образования РФ, обладатель почетной грамоты Президента РФ, докт. техн. наук, профессор. Специалист в области фундаментостроения, обследования и реконструкции зданий. Член Президиума Российского общества по механике грунтов, геотехнике и фундаментостроению, обладатель медали Н.М. Герсеванова. Автор, соавтор 8 монографий, 2 региональных нормативных документов, 18 учебных и научно-практических пособий, 3 справочников, 40 патентов РФ на изобретения, всего более 260 научных печатных работ. (Россия, 350044, г. Краснодар, ул. Калинина, 13, E-mail: ofpai@mail.ru).

Arkady A. Petukhov. Director of LLC “Stroytechinovations TDSK” (Tomsk), Associate Professor of the Department of “Foundations and Foundations” of I.T. Trubilin Kuban State Agrarian University (Krasnodar), Candidate of Technical Sciences, Associate Professor. He is a specialist in the field of engineering-geological surveys, reconstruction of buildings and geotechnical construction. Author and co-author of more than 80 scientific works, 30 patents of the Russian Federation for inventions and utility models. (Russia, 350044, Krasnodar, 13, Kalinina str. E-mail: paa5579@mail.ru)

Петухов Аркадий Александрович. Директор предприятия ООО «Стройтехинновации ТДСК» (г. Томск), доцент кафедры «Основания и фундаменты» Кубанского государственного аграрного университета им. И. Т. Трубилина (г. Краснодар), канд. техн. наук, доцент. Специалист в области инженерно-геологических изысканий, реконструкции зданий и геотехнического строительства. Автор, соавтор более 80 научных работ, 30 патентов РФ на изобретения и полезные модели. (Россия, 350044, г. Краснодар, ул. Калинина, 13, E-mail: paa5579@mail.ru).

Nadezhda S. Nikitina, Director of the Publishing House of the Association of Universities for Civil Engineering (Moscow), Professor of the Department of Soil Mechanics and Geotechnics of the National Research Moscow State University of Civil Engineering (NRU MGSU), Candidate of Technical Sciences, Professor. Scientific and practical interests: soil mechanics, foundation engineering, geotechnical construction; educational activity in the field of training of scientific and pedagogical personnel in postgraduate studies. Honorary worker of higher professional education of the Russian Federation, author of more than 50 scientific works. (Russia, 129337, Moscow, Yaroslavskoe Shosse, 26, High-Rise Building, office. 511; E-mail: nsnikitina@mail.ru).

Ivan V. Semenov. Senior lecturer, postgraduate student at the Department of "Bases and Foundations" of Kuban State Agrarian University named after I.T. Trubilin. Scientific and practical interests: improvement of constructive solutions of injection, bored-injection piles and methods of their calculation, computer support of scientific and design works in construction. Author, co-author of 5 scientific-practical and educational-methodical manuals, 1 monograph, 25 scientific articles and 4 patents of the Russian Federation for inventions. (Russia, 350044, Krasnodar, 13, Kalinina str., E-mail: amigos_siv@mail.ru)

Никитина Надежда Сергеевна. Директор издательства Ассоциации строительных ВУЗов (Москва), профессор кафедры механики грунтов и геотехники Национального исследовательского Московского государственного строительного университета (НИУ МГСУ), канд. техн. наук, профессор. Научно-практические интересы: механика грунтов, фундаментостроение, геотехническое строительство; образовательная деятельность в сфере подготовки научно-педагогических кадров в аспирантуре. Почетный работник высшего профессионального образования РФ, автор более 50 научных работ. (Россия, 129337, Москва, Ярославское шоссе, д. 26, Высотное здание, оф. 511; E-mail: nsnikitina@mail.ru).

Семёнов Иван Владимирович. Старший преподаватель, аспирант кафедры «Основания и фундаменты» Кубанского государственного аграрного университета им. И. Т. Трубилина. Научно-практические интересы: совершенствование конструктивных решений инъекционных, буроинъекционных свай и методов их расчета, компьютерное обеспечение научных и проектных работ в строительстве. Автор, соавтор 5 научно-практических и учебно-методических пособий, 1 монографии, 25 научных статей и 4 патентов РФ на изобретения. (Россия, 350044, г. Краснодар, ул. Калинина, 13, E-mail: amigos_siv@mail.ru).