Main reasons for strengthening foundations and base soil stabilizations of used buildings

A I Polishchuk\textsuperscript{1,2}, I V Semyonov\textsuperscript{1} and V A Demchenko\textsuperscript{1}

\textsuperscript{1}Department of Bases and Foundations, Kuban State Agrarian University named after I T Trubilin, Krasnodar, 13 Kalinina Street, Russia

\textsuperscript{2}ofpai@mail.ru

Abstract. The paper considers main reasons of strengthening foundations and base soil stabilizations of used buildings. We analyzed more than 120 buildings with various design solutions, which were operated mainly on clay soils, identified reasons and divided them into four groups. The first group is reconstruction of buildings, including their restoration and complete overhaul. The second group is the material destruction of the foundations and a decrease in their waterproofing qualities. The third group is a violation of the stability conditions of foundations during the operation of buildings (structures). The fourth group is the development of significant deformations of buildings during their operations.

1. Introduction
This work has been made on the basis of the analysis and generalization of the survey results of more than 120 buildings of various design solutions and ages, which were operated mainly on clay soils. In the course of constructions and operations, the buildings in question were deformed by various reasons, which were found during the examination of their conditions. The survey (visual, instrumental) included the assessment of the strength and deformation characteristics of the building structures (including foundations), base soils, performing verification calculations, clarifying the categories of the technical condition of buildings, groups specified later (sections 2-4). The paper uses materials published in the works of Abelev M. Yu., Dalmatov B. I., Konovalov P. A., Roitman V. M., Sorochan E. A., Ulitskiy V. M., Tsytovich N. A., Shvets V. B. and others [1 to 15].

2. Materials and Methods
The survey of the foundations was carried out from pits, which were laid in the most characteristic places of the building plan. These pits were simultaneously used to survey the basement soils. The number and dimensions of the pits were determined by the dimensions of the building being examined and its design features, the soil conditions of the construction site, the condition of the foundations and other above-ground building structures. In buildings with a basement, the pits were usually laid inside the basement, which made it possible to reduce the amount of earthwork during their sinking.

When examining the foundations in the open pits, the type of foundations, their shape in plan, dimensions, and depth were specified. At the same time, the strength of the foundation material was determined and masonry defects (for strip, stone and concrete foundations), the presence of cracks, as well as previously performed connections and reinforcements were identified. The strength of the
foundation material was determined by destructive and non-destructive methods. This depended on the solution of the problems set during the survey, available instruments and equipment.

When examining the long-term operated buildings, special attention was paid to waterproofing basement walls and foundations, as well as the regime of changing the level of groundwater. In large cities, an increase in the level of groundwater is often noted, due to water leaks from external sewerage networks, water supply systems, heating mains, violations of the engineering preparation of territories and other reasons. Therefore, when examining the foundations and soils of the base, sources of soaking were found to subsequently provide technical solutions for their elimination.

Based on the examination results of the foundations (including the soils of the base), taking into account the revealed defects and damages, an assessment of their technical condition (visual, instrumental) was given [2]. During the assessment, the nature and direction of the development of cracks, the boundaries of areas of local destructions or rupture of foundations, the place where the bases were soaked were determined and the category of their technical condition was established (according to the current regulatory documents SP 13-102-2003, GOST 31937-2011, etc.). When assessing the technical condition of the foundations (including the basement soils) and other above-ground building structures, the issue of defect or damage causes has always been important.

3. Results

3.1. Reconstruction of buildings

Reconstruction of buildings, including their restoration and overhaul, is almost always associated with an increase in loads on the bases and foundations. At the same time, both permanent and temporary loads increase due to the replacement of outdated technological equipment and an increase in the density of its placement, a bridge installation and overhead cranes of higher carrying capacities, the replacement and strengthening of individual building structures, etc. As a result of the increase in loads, the pressure at the bottom of the foundations in operation buildings (structures) may exceed the design soil resistance of the foundation, on the basis of which they were designed before reconstruction [3, 4]. This makes it necessary to strengthen the foundations by increasing the size of the sole (support area), strengthening the soils of the bases or in other ways (figure 1).

![Figure 1](image1.jpg)

**Figure 1.** Increase in loads on foundations, foundation soils during the reconstruction of an industrial building (work on the additional floor): (a), (b) respectively, the beginning and completion of the reconstruction of the building.

The accumulated experience in the reconstruction of buildings shows that with an increase in the loads on building structures, it is recommended to reinforce the foundations (strengthening of the foundations) in the case when there is no reserved bearing capacity of the foundation soils [5, 6].
3.2. Destruction of the foundation material and a decrease in its waterproofing qualities

Studies have established that destructions of foundation materials and decreases in their waterproofing qualities often occur as a result of an impact of aggressive groundwater [4]. Their appearance at the base of foundations is associated with the dissolution of salts in soils (loess and saline soils), leaks of chemical solutions from technological pipelines and sewer networks, etc. When salt solutions interact with foundation structures, a great pressure arises in the pores of the foundation material due to the crystallization of salts. This leads to a decrease in the strength of concrete, solution of rubble or brickwork and a gradual destruction of foundations (figure 2).

Figure 2. Destruction of brickwork of foundations (basement part) of buildings as a result of exposure to aggressive groundwater: a), (b) respectively, on different buildings.

The need to strengthen foundations due to their destruction is sometimes caused by various dynamic impacts. Vibration of mechanisms, an influence of shocks from the movement of transport and the operation of technological facilities, driving piles near existing buildings and other dynamic influences can lead to spalling of the solution and stratification of rubble masonry, the appearance of cracks, chips in concrete and reinforced concrete foundations [7].

Quite often, destructions of foundation materials and lower sections of the walls occur as a result of a waterproofing violation (figure 3). This is especially typical for old buildings built on rubble and brick foundations. Over a long period of building operations, a cultural layer around them gradually increases due to filling and asphalting of courtyard areas, raising the marks of roads and sidewalks near buildings. As a result, the horizontal waterproofing is much lower than the outer surface of the base, and the water in the ground freely penetrates the masonry of walls and foundations by reducing their strength. The absence or malfunction of the blind area around buildings (structures) also contributes to the unhindered penetration of atmospheric water into the base and pores of the foundation material. All this creates unfavorable conditions for the work of foundations, especially in the most loaded places. Seasonal freezing and thawing of moisture in the soil and foundation masonry for a long time lead to deformation of the basement walls, foundation structures and their destruction [8, 9].

There are cases of destruction of foundation materials during fluctuations in the level of groundwater. The most typical example of the foundation destructions is the decay of wood piles in the place of their abutment to the grillage with a sharp drop in the level of groundwater caused by the laying underground pipes, engineering preparation of territories and other reasons. However, when wooden piles are constantly in water, their lifespan can be 100–150 years or more. Consequently, with an appropriate justification, such foundations can also be operated with increased loads caused by the reconstruction, restoration and overhaul of buildings.
Sometimes in reinforced concrete foundations, reinforcement is destroyed as a result of its corrosion (figure 4). These processes occur most intensively in the presence of stray currents or the influence of an aggressive environment (solutions of salts, acids, alkalis). Corrosion leads to a decrease in the diameter of the reinforcement, which is especially dangerous for slab parts of foundations (cushions). Cracks develop in the foundation cushions, the area of the foundation base, which transfers pressure from the structure to the ground, decreases, and, therefore, significant additional base settlements occur.

![Figure 3. Destruction of the brickwork of the walls of the building basement as a result of a waterproofing violation: (a), (b) respectively, on different buildings.](image1)

![Figure 4. Destruction of the working reinforcement in the socket-type concrete foundations of walls during corrosion: (a), (b) respectively, in different foundations.](image2)
3.3. Violation of the stability conditions of foundations

Violation of the stability conditions of foundations during the operation of buildings occurs for several reasons. Most often this is due to additional soil moisture, which occurs when the hydrogeological conditions of the site change, emergency water leaks from engineering systems (water supply, sewerage, heat supply networks), improper planning of territories, etc. [10]. As a result of the additional moistening, the physical and mechanical properties of soils deteriorate and the base is weakened. At the same time, the strength characteristics of the soil have a significant effect on the stability of the foundations. In some types of clay soils, when moistened, the characteristics of specific cohesion and, to a lesser extent, the angle of internal friction are sharply reduced. This leads to the appearance of an unacceptable settlement of foundations and deformations of other building structures; there is a danger of losing the bearing capacity of the foundation and the possibility of its failure. In some cases, the foundation weakening as due to a decrease in the strength characteristics of the soil brings the building in an emergency state (figure 5).

![Figure 5. Development of cracks in the load-bearing walls of a civil building due to an uneven settlement of foundations.](image)

There cases of stability violations of foundations under dynamic influences, karst-suffusion processes with the formation of sinkholes under the foundations, with intensive decay of organic matter contained in the soil, as well as with additional moisture of subsiding, swelling and saline clay soils. Violations of the foundation stability conditions are also observed on seasonally frozen soils, which is due to the foundation thawing when heat flows penetrate into it, and in some other cases [11, 12]. Thus, the stability violation of foundations leads to a serious damage to the buildings in use and causes the need for labor-intensive repair and restoration works.

3.4. The development of significant deformations of buildings

The development of significant deformations of buildings is more often caused by mistakes made during engineering and geological surveys, design and construction of buildings (structures), as well as during their operations.

The most common mistake in engineering and geological surveying is the insufficient volume of work performed (M.Yu. Abelev, 1983; R.A. Mangushev, M.S. Zakharov, 2014). An insufficient number of drilled wells and pits, a small number of samples and monoliths taken lead to distortion of information about the properties of base soils. As a result of lack of reliable information on the lithological structure of the site at a certain depth from the basement base, there may be engineering-
geological elements (or lenses) of peat, silty or other weak heterogeneous soils with organic inclusions that are compressed under load and undergo decomposition, which causes the development of inadmissible deformations of buildings. Due to an insufficient amount of surveys, there may be no information about the presence of karst phenomena and underground workings at the base. When conducting engineering-geological surveys, sometimes there are cases of incorrect determinations of soil properties, mainly strength and deformation. This is due to violations of requirements for selection, transportation and storage of soil samples.

Distorted data on soil properties can be obtained with errors in predicting changes in groundwater levels and a general assessment of the hydrogeological conditions of the site. There are known examples of obtaining distorted data on the strength and deformation characteristics of soils as a result of incorrectly adopted research methods, as well as due to an insufficient attention to the chemical properties of groundwater, the presence of rapidly dissolving salts in the basement (M. Yu. Abelev, 1975, 1993).

Errors in the design of foundations include an incorrect assessment of the specific properties of soils and the bearing capacity of the foundation during freezing and thawing of seasonally frozen soils, a probable rise in the level of groundwater, penetration of solutions of salts, acids and other chemicals into the soil. Underestimation of construction features in areas where subsidence, swelling, saline and other structurally unstable soils, as well as foundations with deep seasonal freezing, often lead to unacceptable deformations of buildings and structures (figure 6). Errors in design are caused by underestimation of the composition and nature of the transfer of loads acting on the foundations. With multiple repeated alternating loads, additional precipitation and unacceptable rolls of structures may occur (V.A. Ilichev, 1992; L.R. Stavnitser, 2010).

![Figure 6. The development of cracks in the bearing walls of civil buildings due to an underestimation of their construction features: (a), (b) respectively, the operation of buildings on loess subsidence and seasonally frozen soils.](image-url)

The development of significant deformations of buildings and structures is sometimes caused by incorrectly selected calculation schemes and calculation methods during engineering designs. There were cases of designing buildings on highly compressible soils, when designers did not envisage measures to increase the spatial rigidity of the building, which led to unacceptable cracks in the walls and deformations of other building structures (figure 7) [13, 14]. The absence of sedimentary seams at the junction of parts of a building of different floors, as well as a significant difference in pressures
along the bottom of the foundations of the same building caused uneven settlements of the foundations (P.A. Konovalov et al., 2011; A.I. Polishchuk et al., 2019). There are also known examples when, as a result of erroneously accepted design schemes when designing individual foundations and grillages for columns, the bottom of a reinforced concrete glass was pushed through (A.M. Boldyshev, A.I. Malganov, 1980–1986).

![Figure 7. A crack in a brick wall of a public building due to a significant difference in pressures along the bottom of the foundations.](image)

Errors made in the construction of bases and foundations are most frequent in construction practice and develop unacceptable deformations [2]. Problems arise when a soil structure is disturbed due to an improper organization of work on water lowering of the site and pumping water from the excavations, with an intensive drying of the bottom of the pits after soaking with atmospheric waters, when developing trenches and other excavations on sites with weak clayey soils. The development of unacceptable deformations of buildings and structures during construction sometimes occurs due to freezing and thawing of the soil with an untimely filling of the sinuses of the foundations or a lack of protection of the foundations from freezing (M.A. Malyshiev, V.V. Fursov et al., 1992) [11].

In construction practice, there are cases of no control over the quality of the work performed; bases and foundations are arranged in violation of the building codes. Typical examples are pile sinking with deviation from the design position, poor-quality compaction of bedding at the base of foundations, freezing of concrete of foundation structures, laying of a concrete mixture of monolithic grillages along contaminated pile heads. Often, builders consider it unnecessary to protect the outer and inner walls of basements from the effects of groundwater by means of waterproofing, clay locks and waterproof screens, surface water runoff, blind areas and sidewalks around buildings. Problems in the construction and operation of buildings can arise if the pre-construction compaction of the foundations, composed of weak water-saturated clay, peat and other structurally unstable soils, is not performed. Sometimes deformations of buildings in operation took place during constructions of trenches, pits and foundations of structures near these buildings.

Errors made during operations of buildings and structures also cause their uneven deformations. Most often, deformations of structures in this case occur as a result of soaking the soils with water, fecal wastewater and technological solutions entering the base from faulty engineering systems.
Violation of the normal operation of buildings also occurs when the load-bearing building structures of the floors are overloaded due to the installation of additional equipment, as well as when the thickness of the attic insulation or the roof of buildings increases. Problems during the operation of buildings also arise when the temperature and humidity conditions are violated inside the premises, when the openings in reinforced concrete walls are improperly arranged, and in other cases. The above violations of operations of buildings made it possible to compile a classification of the main reasons for the need to strengthen the foundations and harden the soils of bases (figure 8).

**Figure 8.** Classification of the main reasons for the need to strengthen foundations and harden foundation soils.

4. Discussion
The need to strengthen (reorganize) foundations, harden foundation soils usually arises during reconstructions of buildings, including their restoration and major repairs. For example, the solution of such issues has to be faced with manifestations of uneven settlements of foundations, the alignment of the banks of buildings (structures), laying of underground utilities, defects and damage to building...
structures, arrangement of foundations in cramped conditions, as well as some other cases when the normal operation of buildings is disrupted. The main reasons established during the survey caused the need to strengthen foundations and harden soils of foundations. They were combined into four groups (figure 8). The first group is the reconstruction of buildings (structures), including their restoration and major repairs. During reconstruction, as a rule, there is an increase in the loads on the foundations (permanent and temporary) due to replacement of technological facilities and an increase in its density. Reconstruction can also be caused by adding floors, changes in the structural design of building roofs and other reasons, as a result of which there is a need to strengthen foundations and harden foundation soils. The second group of reasons is the destruction of a foundation material due to a prolonged exposure to aggressive groundwater. Such water appears at a foundations base during its transportation from a faulty water supply and sewerage networks. As a result of a long-term interaction of underground building structures with industrial water (including aggressive water), their waterproofing (vertical, horizontal) is violated and foundations, underground walls of buildings lose their operational reliability. The third group of reasons is the violation of the stability conditions of foundations during the operation of buildings (structures). Such reasons occur with additional moistening of the soil at the base of the foundations, with dynamic effects on the base, with periodic changes in the temperature and humidity conditions of the soil at the base, etc. The fourth group of reasons is the development of significant deformations of buildings and structures. The reasons for this group appear most often due to mistakes made during engineering and geological surveys, design, construction and operation of bases and foundations of buildings (structures). There may be other reasons for the need to strengthen the foundations and harden the soils of the foundations (construction of tunnels, subways, other underground works, etc.).

5. Conclusions
Thus, the generalization performed shows that in the conditions of reconstruction and restoration of buildings, it becomes necessary to strengthen foundations and harden foundation soils. When solving these issues, it is necessary to assess technical building structures (taking into account the base soils) and the serviceability of buildings, as well as identify causes of their deformations and destruction.

References
[1] Malganov A I, Plevkov V S and Polishchuk A I 1992 Restoration and strengthening of building structures of emergency and reconstructed buildings (Tomsk: Publishing house Tomsk)
[2] Polishchuk A I and Tarasov A A 2016 Handbook of geotechnics: bases, foundations and underground structures. Chapter 16. Strengthening the foundations and foundations of buildings and structures ed Il'ichev V A and Mangushev R A (Moscow: Publishing house ASV) pp 807-50
[3] Polishchuk A I 2000 The purpose of the design soil resistance of the foundation when designing the foundations of reconstructed buildings Soil Mechanics and Foundation Engineering 3 5 6–10
[4] Polishchuk A I 2007 Fundamentals of design and installation of foundations of reconstructed buildings vol 3 (Northampton: STT; Tomsk: STT)
[5] Polishchuk A I and Semenov I V 2019 Engineering method of calculating injection pile in clayey soils Soil Mechanics and Foundation Engineering no 5 6 pp 23-28
[6] Polishchuk A I and Semenov I V 2020 Design of reinforcement of foundations of reconstructed, restored buildings using piles Construction and Geotechnics 11 (4) 33–45
[7] Mangushev R A, Gotman A L, Znamensky V V and Ponomarev A B 2018 Piles and pile foundations. Structures, design and technologies (Moscow: Publishing house ASV)
[8] Yushchube S V, Polishchuk A I and Fursov V V 2000 Method of making bored injection piles in seasonally freezing soil Patent RU no 2150550
[9] Polishchuk A I and Efimenko S V 2005 Investigation of the composition and properties of clay soils in the regions of Western Siberia for the purpose of their design characteristics Bulletin of TSUAB 1 213
[10] Abelev M Yu 1983 Construction of civil and industrial structures on weak water-saturated soils
[11] Malyshev M A, Fursov V V, Balyura M V and Rozhdestvenskaya L A 1992 Bases and foundations of buildings in conditions of deep seasonal freezing of soils (Tomsk: Publishing house of Tomsk University)

[12] Polishchuk A I and Efimenko S V 2005 Estimated values of the characteristics of clay soils for the design of auto-mobile roads News of higher educational institutions. Construction 8 5 66–71

[13] Polishchuk A I 2016 Analysis of soil conditions of construction in the design of building foundations (Moscow: Publishing house ASV)

[14] Tonkikh G P, Morozov A S and Demidov K A 2010 Album of constructive solutions for seismic reinforcement of stone buildings and structures ed Tonkikh G P and Kabantseva O V (Tomsk; Moscow: Publishing house "Printing manufacture")

[15] Konovalov P A and Konovalov V P 2011 Bases and foundations of the reconstructed buildings vol 5 (Moscow: Publishing house ASV)