IOP Conference Series:
Earth and
Environmental Science

PURPOSE-LED PUBLISHING™

PAPER • OPEN ACCESS

Experience in the construction of building superstructures without strengthening their soil bases and foundations

To cite this article: Vynnykov Yuriy *et al* 2026 *IOP Conf. Ser.: Earth Environ. Sci.* **1638** 012049

Experience in the construction of building superstructures without strengthening their soil bases and foundations

Vynnykov Yuriy[1*], Kharchenko Maksym[1], Sukhodub Oleksandr[1], Marchenko Valentyn[2] and Aniskin Aleksej[3]

[1] Department of Drilling and Geology, National University "Yuri Kondratyuk Poltava Polytechnic", Poltava, Ukraine
[2] LLC "Scientific and Technical Company "ALMAGROUP", Poltava, Ukraine
[3] Department of Civil Engineering, University North, Varazhdin, Croatia

[*]E-mail: nning.vynnykov@nupp.edu.ua
0000-0003-2164-9936
0000-0002-1621-2601
0009-0000-3396-017X
0009-0006-9614-1765
0000-0002-9941-1947

Abstract. The article presents the results of range of geological-engineering investigations, geotechnical design and monitoring of superstructures of civil buildings with shallow foundations on natural bases and with pile foundations without additional reinforcement of existing foundations or their bases strengthening. In the design of superstructures, it is proposed to consider the factors aimed at realizing the strength reserves of the structures foundations bases: 1) the primary regulatory base for design of objects; 2) changes in parameters of the existing structural scheme of building; 3) possible compaction (strengthening) of soil directly under bottom of foundation or pile end due to its long-term compression. The article presents the relevant methods and results of field investigations of bases and foundations of existing buildings, static load tests of individual piles that have been loaded for a long time as part of pile group, laboratory tests of physical and mechanical properties of natural and long-term compressed clay (saturated loess) soil, and geotechnical monitoring of buildings and structures. In the reconstruction of a building with an extension and a superstructure, a three-dimensional version of the finite element method was tested for simulation of the stress-strain state of the "base - foundation - building" system, which changes significantly during the stages of project implementation, and the calculated base of foundation settlements with the settlements obtained by levelling at the surface marks established in the building basement were compared.

1. Introduction

According to civil engineering codes [1, 2], during geotechnical investigations, design, construction and exploitation of buildings and structures, as well as during their reconstruction

IOP Conf. Series: Earth and Environmental Science **1638** (2026) 012049 doi:10.1088/1755-1315/1638/1/012049

or superstructure, a geotechnical engineer must ensure a certain level of reliability of "base - foundation - building" system. It should be noted that this concept is comprehensive and includes three main components: reliability, failure, and durability. For new buildings, as well as for reconstruction and superstructures, this system is designed so that the deformations of its foundation do not exceed their limit values, in particular, for new buildings - the limit settlements S_u, the relative difference of foundation settlements $(\Delta S/L)_u$ and tilts i_u, and for superstructures (reconstruction) - similar additional parameters, the values of which depend on technical condition of the structure.

As geotechnical experience shows, the reconstruction of historical, civil and residential buildings and industrial structures is applied to eliminate physical deterioration and of these objects or their obsolescence [3, 4, 5, 6]. Reconstruction process is usually accompanied by replacement or strengthening of structure's parts, strengthening of foundations, changes in the size of structures (e.g. annexes, superstructures), etc.

The most popular structural and technological operations in the reconstruction and superstructure of objects are 1) re-profiling of buildings for their intended purpose; 2) replacement of columns, inter-floors and roofs, beams, prefabricated stairwells, balconies with prefabricated concrete structures; 3) extension of additional floors, conversion of attics (high attic) for an additional floor, reconstruction of existing premises; 4) creation of additional floors of lower height and window openings within the existing volume of building; 5) modification of equipment of industrial facilities, etc. Most often superstructures are used for buildings that are less than 50 years old.

2. Problem statement

Of course, implementation of such projects almost always causes an increase of load on foundations of existing buildings, and, accordingly, pressure on their soil bases. Special engineering and geological conditions of sites (e.g., loess subsidence soils, weak sediments, flooded areas, etc.) add to the problems, where the operation of facilities is associated with possible manifestations of uneven deformations, cracks in load-bearing structures, and deterioration of operational parameters of buildings and structures [7, 8].

Calculations of natural soil bases of shallow foundation [9, 10] or the so-called foundations with soil excavation [11], both for design of new buildings and superstructures (reconstruction), are classically based on solutions of the theory of linearly deformed half-space, that is, to determine the settlement of foundations, the average pressure under the foundation footing p should not exceed the value of calculated soil resistance R (it depends on the type and condition of soils, their unit weights and strength characteristics, foundation parameters, and building stiffness). And the value of settlement of structures soil bases is usually calculated by method of layer-by-layer summation, etc.

Soil bases of pile foundations [12, 13, 14] or so-called foundations constructed without excavation [15] are evaluated both by bearing capacity of surrounded soils of piles and by their soil bases deformations.

During engineering and geological investigations of existing buildings, samples of natural structure sediments and, if necessary, long-compressed soils under the foundation footings are taken from boreholes, after which their physical and mechanical properties, primarily void ratio e, elastic (deformation) modulus E, internal friction angle φ, unit cohesion c, etc. are determined by standard laboratory methods [16, 17, 18]. Some experimental studies have shown that, when compaction has been over than 10 years at ratio of $p/R \geq$ 0.5-0.7, compacted soil zone up to 0.35-

0.5 m thick can form under footings. At the same time, new water-colloidal bonds between particles may arise in clayey soils, including loess soils. Occasional static tests of individual piles that have been loaded for a long time as part of a pile group are known. In both cases, empirical logarithmic dependencies are proposed for growth of soil strength and pile bearing capacity, respectively, but such studies are required in every geotechnical design [15].

Regarding the prediction of induced values (after continued compression or compaction) of soil properties, it makes sense to distinguish two relatively new analytical directions: 1) numerical simulation of consolidation of water-saturated soil massifs [19, 20]; 2) simulation, usually by an axisymmetric solution of the problem by finite element method (FEM) in a physically and geometrically nonlinear formulation of fast-moving soil compaction processes around the indentation [21, 22, 23].

The following constructive and technological approaches to strengthening existing shallow foundations on natural bases have been most widely tested [24]: 1) strengthening of foundation structure, for example, by installing cages (banquettes); 2) placing slabs (or pillars or walls) under footings of foundations; 3) construction of new foundations with dismantling of existing ones; 4) underpinning using the "wall in the ground" technology, and sometimes using the "top-down" method; 5) transplanting of foundations on various packed or remote piles.

Even more popular for building superstructures are geotechnical methods of strengthening bases of existing foundations [25]: 1) deep compaction of soil massif by cyclic penetration with pneumatic punch, spiral projectile, etc.; 2) reinforcement of foundation with soil-cement elements using jet grouting or drilling and mixing technology; 3) chemical consolidation of foundation, usually through injectors, variants of it depend on type and condition of soil (e.g. cementation, two-solution and one-solution silicification, thermal consolidation, etc.). In this case, schemes of reinforcement of massifs with elements of increased stiffness can be vertical, horizontal, inclined or combined, etc.

Let us highlight the current structural and technological solutions for strengthening existing pile foundations of buildings [26]: pushing piles into stronger soil; installation of additional remote piles; supplying a monolithic slab under pile caps; similar methods of strengthening pile foundation.

When designing a superstructure, stress-strain state (SSS) of “base - foundation - building” system should be assessed both during its previous operation and when bases and foundations are strengthened, as well as when the load on foundations increases due to superstructure. Three-dimensional (3D) and sometimes two-dimensional (2D) versions of SSS with the use of sufficiently tested elastoplastic soil models are most approved [27, 28] to obtain visually the parameters of FEM of this system.

Also, simulation modelling techniques based on 3D version of FEM, for example, using Hardening Soil Model, have already gained popularity, as well as the influence of soil heterogeneity parameters and foundation components or reinforcement elements on SSS system [29, 30].

3. The purpose of the study

If by the codes analyse SSS of “base - foundation - building” system or its components when superstructing an object as for new construction, there is a high probability that existing foundations will need to be reinforced or their bases strengthened.

However, such structural and technological solutions, although highly efficient, are complex and require high labour intensity and duration. The experience of reconstruction and

IOP Conf. Series: Earth and Environmental Science **1638** (2026) 012049 doi:10.1088/1755-1315/1638/1/012049

superstructures of buildings has many examples and proven methods of increasing the load on their foundations without measures to improve geotechnical qualities of these bases and/or foundations.

For example, in the mid-20th century, building codes limited the amount of pressure on soil foundation to a much lower value than its bearing capacity (because the achievements of nonlinear soil mechanics methods had not yet been implemented in geotechnical design practice). Also, due to continued compression of soil under the bottom of foundation or pile (as a result of their subsidence), it is possible to form additional reserves of its strength.

Thus, the purpose of the study is to analyse geotechnical aspects of the author's experience of superstructures of civil buildings with shallow foundations on natural bases and with pile foundations without additional strengthening of their soil bases and strengthening of structure of existing foundations.

4. Results of experimental natural studies

In order to develop geotechnical designs of superstructures, the authors take into account a number of factors aimed at realising the strength reserves of soil bases of these structures: 1) the primary base of building codes for the design of structures (year of their construction, relevant design standards and structural schemes); 2) change in the parameters of existing structural scheme of building; 3) possible compaction (strengthening) of soil directly under the foundation footing or pile due to its long-term compression, etc.

The Geotechnical School of National University "Yuri Kondratyuk Poltava Polytechnic" under the leadership of Prof. M. Zotsenko has successfully implemented several dozen of such projects, mainly in clay (saturated loess) soils. All the superstructured buildings have been in successful operation (some of them for over sixty years).

4.1 Examples of building superstructures with foundation on natural soil bases without reinforcement of their bases and foundations

A two-storey public building with longitudinal load-bearing brick walls (mostly 770 mm thick), without a basement floor, with shallow natural foundations was built in the central historical part of Poltava in 1914. Its floors are supported by wooden beams.

Pictures of the example of engineering and geological investigation of this building for construction of superstructure are shown in Figure 1. The site is located in flat part of Poltava loess plateau. The thickness of loess layer is up to 9.3 m. There is no subsidence of soil from its own weight during saturation. Lithological soil profile is represented by heavy and light dusty loams up to a depth of 12 m. The groundwater level was 6.8 m from the ground surface. Unfavourable physical and geological phenomena within the site include subsidence, flooding of the territory, and non-building (filled) soils with a thickness of up to 2.6 m in some places.

The foundations are strip, brickwork with limestone mortar, shallow (constructed with soil excavation), natural-based. The actual width of their footing is 1000 mm, and the depth of footing is 2.75 m from the surface level in the courtyard of the building and 2.2 m from the facade. The technical condition of both building and foundations is satisfactory.

The bearing soil layer of foundations is a loess loam, heavy silty, stiff plastic, softly plastic, macroporous in degraded state. It has the following calculated mechanical properties: internal friction angle φ_{II} = 23°; unit cohesion c_{II} = 19 kPa; elastic (deformation) modulus E = 3.5 MPa. No significant soil strengthening was observed below the foundation footing.

a

b

c

d

Figure 1. Engineering and geological investigations of a two-storey building with shallow foundations on a natural base: a - building before superstructure; b - pit from which bases and foundations of the building were investigated; c - sampling of rings with long-term compressed soil from under the foundation footing; d - building after its superstructure with an attic floor.

The ratio of the average pressure under the foundation footing to the calculated soil resistance was only p/R = 0.60-0.69, which explains the practical absence of a compacted zone under foundation. As a result of superstructure, this ratio increased to p/R = 0.66-0.77. Accordingly, additional subsidence of foundation bases from the superstructure will be 0.25-0.3 cm, which is less than its limit value of $S_{d.u}$ = 1 cm, and additional relative uneven subsidence will not exceed $(\Delta S/L)_{d.u}$ = 0.0005. Thus, the requirements for calculating the deformations of the building foundations both before and after superstructure are fulfilled.

As a result, a building superstructure with a light attic floor consisting of a load-bearing reinforced steal concrete floor (since the load-bearing capacity of the wooden beams of attic floor was insufficient for mansard floor) and steel enclosing frames with mineral wool insulation was proposed and implemented (Fig. 1 d).

The next, more complex example is the reconstruction of a one-storey building of a non-grocery store with a basement floor with its extension and superstructure in Poltava.

The methodology the building investigation was generally like the previous example. The structural scheme of the building is mixed (load-bearing elements - a grid 6x6 m of reinforced concrete columns, as well as longitudinal and transverse brick walls).

The foundations are shallow on a natural soil base, monolithic, striped under the walls (their footing width is 1.1 m, the depth of foundation is 0.1 m under basement floor level, and under the planning level down to the floor level - 2.05 m) and separate under columns (their footing dimensions are 2.2x2.2 m, the depth of foundation is 0.4 m from the basement floor level, and from the planning level down to the floor level - 1.7 m).

The building service life is up to 40 years. The technical condition of both the building and the foundations is satisfactory. Pictures of project implementation are shown in Figure 2.

a b

c d

e f

Figure 2. Engineering and geological investigations and some stages of reconstruction of a one-storey building with its extension and superstructure: a - before the reconstruction; b - examination of base and a separate foundation for the column from a pit in the basement; c - excavation of a pit around the existing facility and dismantling of structures; d - reinforcement of concrete frame columns and brick pillars of outside walls; e - installation of columns of extension and second floor, roof beams; f - the building after its extension and superstructure.

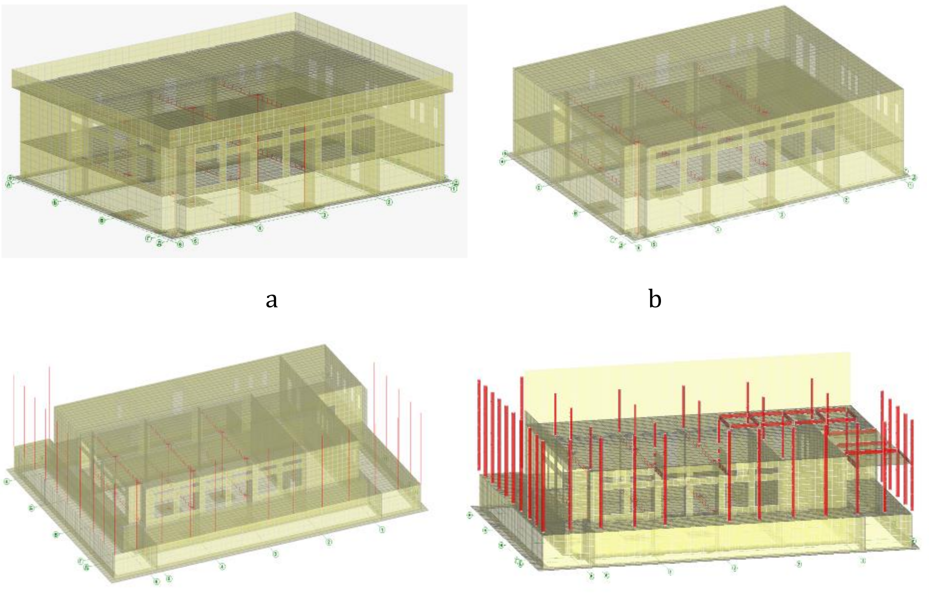
IOP Conf. Series: Earth and Environmental Science **1638** (2026) 012049 doi:10.1088/1755-1315/1638/1/012049

As in the previous example, the site is in the flat part of Poltava loess plateau. The thickness of the loess layer is up to 8.8 m. The soil profile down to 12 m is represented by heavy silty loam and silty sandy loam. Groundwater level is 4.4 m from ground surface.

The bearing soil layer of the foundations is heavy silty loam, semi-hard, soft-plastic, macroporous in degraded state (its calculated mechanical properties are as follows: internal friction angle φ_{II} = 24°; unit cohesion c_{II} = 24 kPa; elastic (deformation) modulus E = 3 MPa), and the underlying layer is silty sandy loam, plastic.

The margin of design resistance of the strip foundation base under the load-bearing wall was only 14%; in other sections, the margin of design resistance of the base was generally sufficient for the superstructure of the building with one floor of lightweight building structures without strengthening its foundations or strengthening their bases.

To analyze SSS of "base - foundation - building" system, which changes significantly at different stages (the state formed during the construction and operation of the structure, demolition of structures, excavation of a pit around the building, extension, superstructure, joint operation of existing and new structures, etc.). The FEM analysis schemes of the facility for individual stages of the project for the reconstruction of a one-story building with its extension and superstructure are shown in Figure 3.



a b

c d

Figure 3. FEM analysis schemes for separate stages of the reconstruction project of a one-storey building with its extension and superstructure: a - before reconstruction; b - during demolition of structures; c - during reinforcement of the ground floor columns and installation of columns on foundations of extension; d - during installation of the second-floor columns and floor beams.

Calculations revealed an increase in forces in reinforced concrete columns of the frame by more than 1.5 times. Therefore, during the reconstruction, they were reinforced, and brick pillars of the outer walls were taken in cages, a monolithic reinforced concrete belt was arranged between the first and second floors, etc.

It should be noted that calculated values of the building foundations settlements were compared with those obtained by levelling the surface marks arranged in the basement of the building. Thus, as a result of dismantling of the structures, the base of strip foundations (they were unloaded more compared to individual column foundations) was uplift up to 1-2 mm.

After the superstructure, the additional settlement of foundations did not exceed 5 mm, which is less than the limit value of $S_{d.u}$ = 1 cm.

The calculated values of settlements are close to the actual ones, which can be easily explained by the fact that during the superstructure, the average pressure under the footings did not exceed the calculated soil resistance.

4.2 An example of a building superstructure with pile foundations without reinforcing their bases and foundations

An eight-storey civil building with pile foundations was built in the seventies of the last century in the central part of Poltava.

An analysis of the available design and construction documents revealed that the building was constructed using precast concrete prismatic piles 10 m long and 300x300 mm in cross-section, which were driven into the ground with a diesel hammer in September 1973. At the time of investigation, the piles had been in service for approximately 44 years from their driving to static load testing (August-September 2017).

The piles are connected to pile groups by separate monolithic reinforced concrete pile caps. Pictures of the engineering and geological investigations of this building for the purpose of its superstructure are presented in Figure 4.

The site is located on the Poltava loess plateau. Its structure down to a depth of 25 m includes the following engineering geological elements (EGEs): IGE-1 - filled soil (layer thickness 1.5-6.8 m); EGE-2 - loess loam, soft plastic (1.6-2.8 m); EGE-3 - loess loam, light (0.4-2.7 m); EGE-4 - heavy, stiffly plastic loams (5.1-6.3 m); EGE-5 - light, softly plastic loams (1.1-1.5 m); IGE-6 - layered clays (4.7-5.6 m); EGE-7 - thin-layered semi-hard clays.

The groundwater level at the time of the surveys was 4-5 m from the ground surface.

Two pits down to 6 m deep were excavated within the contour of the building (Figure 4 b) to expose the pile caps and upper part of piles beneath it.

The technical condition of both the building and its foundations is satisfactory.

The location of two experimental piles, which have been operating for a long time as part of separate monolithic reinforced concrete pile caps, is shown in Figure 5, and the referencing of these pile foundations to soil profile is shown in Figure 6.

A section for the installation of a hydraulic jack was cut out in each test pile directly below pile cap (Figure 4 c).

Two metal angles were rigidly fixed to the test pile below the jack to connect the strings of two deflectometers (0.01 mm scale graduation value) which were fixed to the reference system (Figure 4 e).

Static load tests of soils with piles were carried out in accordance with the building codes. Reinforced concrete pile cap loaded with the weight of the building was used to create a vertical compressive load on the pile. Pile cap used as a stop for hydraulic jack. The tests consisted of applying a load in stages of 70 kN to pile head and records of its settlements. Each load stage was applied until relative stabilization of deformation, which was taken to be an increase of no more than 0.1 mm over 2 hours of observation, after which the next load stage was applied to the pile.

Figure 4. Engineering and geological investigations of an eight-storey building with pile foundations: a - building before superstructure; b - borehole from which the building foundations were examined and static load tests of a single pile that had been loaded for a long time were performed in pile group; c - view from the borehole of the pile in pile group; d - static load tests of a single pile in pile group (hydraulic jack between the pile head and the bottom of the pile cap); e – static load tests of a single pile in pile group (reference system and deflectometers for fixing the pile settlements during its static tests); f - building after its superstructure by one floor.

The pile loading was stopped when the maximum permissible jacking force of 1050 kN was reached, after which the pile was unloaded.

The diagrams of static soil tests with long-term loaded test piles as part of pile group are shown in Figure 7.

They clearly show that no active development of plastic deformations was for both piles.

The bearing capacity of both piles was assumed to be F_d = 770 kN.

Hence, the design (allowable) load to the pile was N = 642 kN.

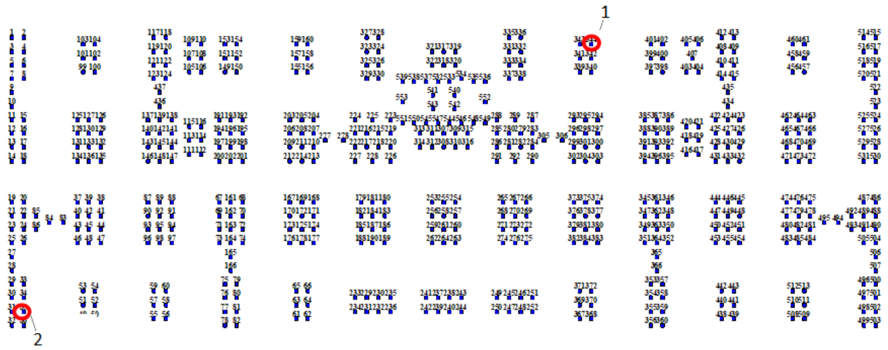


Figure 5. Location of test piles as part of pile caps.

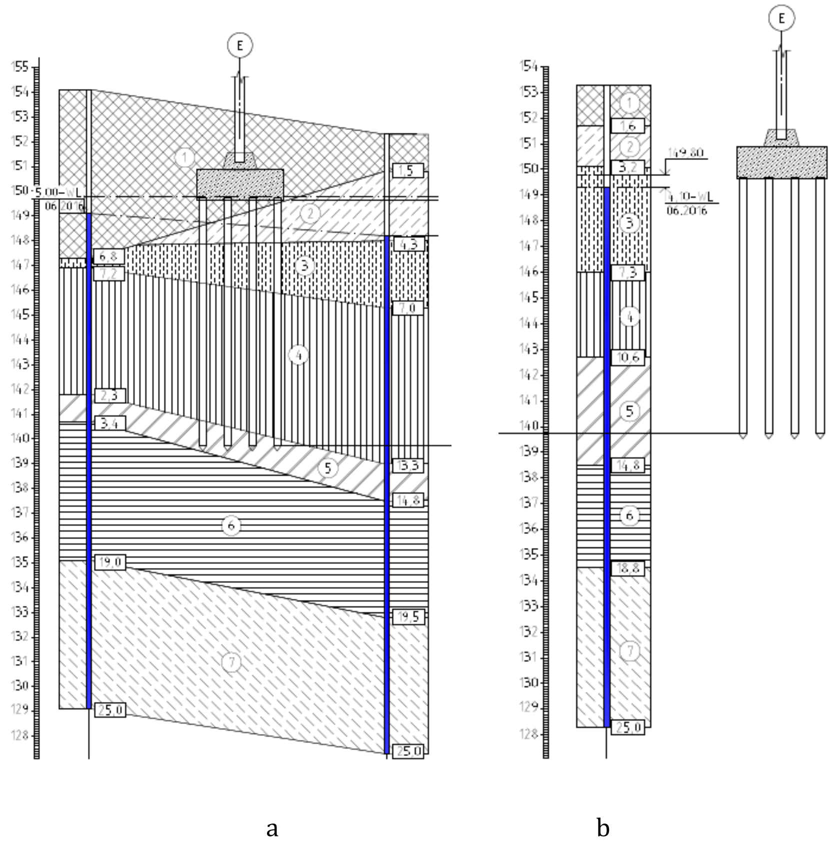


Figure 6. Referencing of pile foundations to soil profile: a - pile No. 1; b - pile No. 2.

It should also be noted that in September 1973, when the piles were driven, dynamic load tests were carried out.

According to their results, the calculated load on the pile was N = 520 kN.

Thus, it can be concluded that during the time the driven prismatic piles were under the design load, the strength of clay soil under the bottom of the pile increased slightly, and accordingly, the bearing capacity of the pile increased (by 19%).

IOP Conf. Series: Earth and Environmental Science **1638** (2026) 012049 doi:10.1088/1755-1315/1638/1/012049

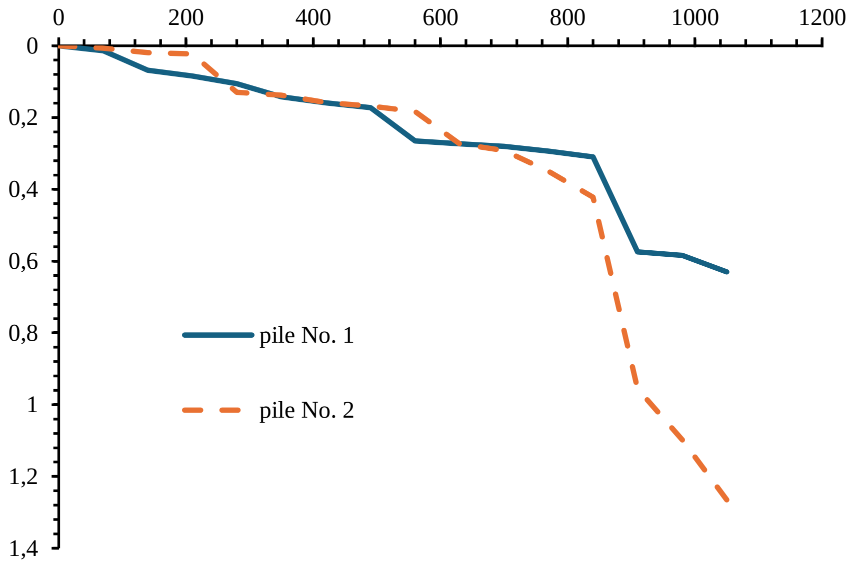


Figure 7. Diagrams of static soil tests with long-lasting loaded test piles as part of pile group.

As a result, a design was developed and implemented to add one floor to an eight-storey building (Figure 4 f).

5. Conclusions

1. With the proper geotechnical investigation, design and monitoring, it is quite possible to achieve high efficiency and reliability of civil engineering superstructures without strengthening their foundations and soil bases. Based on the experience of several dozen similar projects, mostly in clay (saturated loess) soils, all superstructures have been successfully operated (and some of them have been in operation for over sixty years).

2. When designing superstructure projects, it is reasonable to investigate and take into account groups of factors aimed at identifying and implementing strength reserves of soil bases of these structures, such as primary regulatory framework for design of buildings (year of construction, relevant design standards and structural schemes); changes in parameters of existing structural scheme of the building during the superstructure (the installation of a continuous monolithic reinforced concrete belt under the new floor increases both the overall stiffness of the building and the value of calculated soil resistance); possible strengthening of soil directly under the bottom of foundation or pile due to its long-term compression. Field tests have shown that during the time that the driven prismatic piles were under the design load in pile cap, the strength of clay soil under the bottom of pile increased slightly, and accordingly, the bearing capacity of pile increased (by 19%). However, to quantify the increase in soil strength and pile bearing capacity in each geotechnical project, the above-described field and laboratory investigations are obligatory.

3. To estimate SSS of the "base - foundation - building" system, which changes significantly at different stages of reconstruction project of a one-storey building with its extension and superstructure (the state formed during the construction and operation of the building, dismantling of structures, excavation of a pit around the object, extension, superstructure, joint

operation of existing and new system components), 3D version of FEM was tested, which revealed an increase in forces in reinforced concrete columns of the existing frame by more than 1.5 times. Therefore, during the reconstruction, they were reinforced, and the brick columns of the exterior walls were taken in cages, a monolithic reinforced concrete belt was arranged between the first and second floors, etc.

References

[1] European Committee for Standardization (2004) Eurocode 7: Geotechnical design – Part 1: Generalrules (EN 1997-1). Brussels, CEN
[2] EN 1997-2:2007 European Committee for Standardization (2007) Eurocode 7: Geotechnical Design. Ground investigation and testing. Brussels
[3] Savic J, Romić N (2021) Complexity of geotechnical problems in the process of revitalization of residential buildings. Facta universitatis - series Architecture and Civil Engineering 19(1): 55-65
[4] Przewlocki J, Dardzinska I, Swinianski J (2005) Review of historical buildings' foundations. Géotechnique 55(5): 363-372
[5] Popa A, Ilies N M, Farcas V S, Muresan O C, Winter M G, Snith D M, Eldred P J L, Toll D G (2015) Geotechnical Problems on Transylvanian Historical Buildings Consolidation. In: Proc. of the XVI ECSMGE Geotechnical Engineering for Infrastructure and Development, 3547-3552. Edinburgh
[6] Ivashko Y, Dmytrenko A, Paprzyca K, Krupa M, Kozłowski T (2020) Problems of historical cities heritage preservation: Chernihiv art nouveau buildings. International Journal of Conservation Science Vol. 11, Is. 4: 953-964
[7] Zotsenko M, Vynnykov Yu, Doubrovsky M, Oganesyan V, Shokarev V, Syedin V. Shapoval A, Poizner M, Krysan V, Meshcheryakov G (2013) Innovative solutions in the field of geotechnical construction and coastal geotechnical engineering under difficult engineering-geological conditions of Ukraine. In: Proc. of the 18th Intern. Conf. on Soil Mechanics and Geotechnical Engineering. Paris, 3, 2645-2648
[8] Kichasov O (2025) Restoration measures for foundations of metal silos on degraded loess soils. Academic Journal Industrial Machine Building Civil Engineering, 1(64), 103-111
[9] Braja M D (2017) Shallow foundations. Bearing capacity and settlements. CRC Press. Taylor & Francis Group
[10] Evans J, Ruffing D, Elton D (2021) Fundamentals of ground improvement Engineering. Publisher: Taylor and Francis
[11] Zotsenko M, Vynnykov Y, Lartseva I, Sivitska S (2018) Ground base deformation by circular plate peculiarities. MATEC Web of Conferences, 2018, 230, 02040
[12] Fleming K, Weltman A, Randolph M, Elson K (2008) Piling Engineering London and New York: Taylor and Francis
[13] Leung Y F, Klar A, Soga K, Hoult N A (2017) Superstructure-foundation interaction in multi-objective pile group optimization considering settlement response. Canadian Geotechnical Journal. 54(10): 1408-1420
[14] Badelow F., Harry G. Poulos H G (2016) Geotechnical foundation design for some of the world's tallest buildings Japanese Geotechnical Society Special Publication 2(2): 96-108
[15] Zotsenko M L, Vynnykov Y L, Pinchuk N M, Manzhalii S M (2019) Research of influence area parameters of the foundations arranged without soil. IOP Conference Series: Materials Science and Engineering, 708(1), 012076
[16] Fredlund D G, Rahardjo H, Fredlund M D (2012) Unsaturated Soil Mechanics in Engineering Practice. John Wiley & Sons, New York, NY
[17] Das B M (2019) Advanced Soil Mechanics. London: CRC Press
[18] Briaud J-L (2013) Geotechnical Engineering: Unsaturated and Saturated Soils. Hoboken United States: John Wiley & Sons
[19] Edip K, Garevski M, Sheshov V, Bojadjeva J (2015) Numerical simulation of consolidation problem. In: Proc. of the XVI ECSMGE Geotechnical Engineering for Infrastructure and Development, pp. 3847-3850. Edinburgh
[20] Qiu G, Henke S, Grabe J (2011) Application of a Coupled Eulerian–Lagrangian approach on geomechanical problems involving large deformations. Computers and Geotechnics, Vol. 38: 30-39
[21] Mukherjee M, Chand B (2022) Simulation of pile penetration in sand employing Lagrangian and CEL based FE approach: a comparative study. In: Proc. of the 20th Intern. Conf. on Soil Mechanics and Geotechnical Engineering 2, 865-870. Australian Geomechanics Society, Sydney, Australia
[22] Berndt J, Hundertmark A-K, Reul O, Tian Y (2022) Numerical simulation of driven displacement piles with respect to installation effects because of in-situ test results. In: Proc. of the 20th Intern. Conf. on Soil Mechanics and Geotechnical Engineering 2, 937-942. Australian Geomechanics Society, Sydney, Australia

IOP Conf. Series: Earth and Environmental Science **1638** (2026) 012049 doi:10.1088/1755-1315/1638/1/012049

[23] Ni P, Chen Z, Reul O, Mei G (2022) Physical modeling and analytical derivation of soil consolidation around permeable pipe pile. In: Proc. of the 20th Intern. Conf. on Soil Mechanics and Geotechnical Engineering 2, 1151-1156. Australian Geomechanics Society, Sydney, Australia
[24] Zumrawi M M E, Aldaw H K E (2019) A study on Strengthening of Building foundation for Storey Extension Journal of Building Materials and Structures 5(2)
[25] Wanik K (2013) Use of jet grouting technique to realize substructures of historic buildings: The example of an apartment building in Warsaw. In: Proc. of the 2nd International Symposium on Geotechnical Engineering for the Preservation of Monuments and Historic Sites, pp. 769–777, CRC Press-Taylor & Francis Group, Boca Raton USA
[26] Vynnykov Yu L, Kharchenko M O, Manzhalii S M (2021) Reinforcement of a deformed structure on the pile foundation. IOP Conference Series: Materials Science and Engineering. 1021(1) 012030
[27] Chau K (2013) Numerical Methods. In: Proc. of the 18th Intern. Conf. on Soil Mechanics and Geotechnical Engineering, 647-654. Paris
[28] Xu W, Huang X, Huang J, Yang Z (2021) Structural Analysis of Backfill Highway Subgrade on the Lower Bearing Capacity Foundation Using the Finite Element Method. Advances in Civil Engineering 2: 1-11
[29] Dareeju B, Rowles T, Xu Y (2022) Probabilistic modelling of shear strength parameters for tailings dam design. In: Proc. of the 20th Intern. Conf. on Soil Mechanics and Geotechnical Engineering 2, 4537-4541. Australian Geomechanics Society, Sydney, Australia
[30] Randolph M, Buttling S (2022) An investigation of probabilistic analysis in relation to the design of pile groups. In: Proc. of the 20th Intern. Conf. on Soil Mechanics and Geotechnical Engineering 2, 4519-4524. Australian Geomechanics Society, Sydney, Australia