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LOAD TESTING OF BORED CONCRETE MICROPILE WITH ENLARGED BASE IN DISPERSIVE SOIL CONDITIONS

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Abstract. *This article presents the results of field testing of a bored micropile with a base enlargement, installed within the foundation of a two-story civil building located in Lviv region. It is demonstrated that the use of a 350 mm diameter base enlargement of the pile significantly increases its bearing capacity. An engineering-geological survey of the site was conducted, identifying three engineering-geological elements encompassing weak water-saturated silty clay and sandy loam soils. Experimental data on the pile behavior under static compressive loading up to 72 kN were obtained, which is nearly twice the calculated design value of 38 kN. The testing methodology involved stepwise application of the load with simultaneous registration of vertical displacements using high-precision measuring instruments. Based on the test results, a load-settlement curve was constructed, exhibiting a typical behavior with stages of initial deformation, stabilized settlement, and elastic recovery. It is shown that the pile–soil system operates without signs of progressive deformation and demonstrates significant elastic rebound after unloading. The allowable load calculation, considering a reliability factor (γ=1.2), determined the actual bearing capacity of the pile at 60 kN, exceeding the design value by 57%. Hence, the pile design with a base enlargement proves effective for the given engineering-geological conditions and ensures foundation reliability with reduced pile quantity costs. The obtained results confirm the effectiveness of using bored micropiles with base enlargement in low-rise construction and indicate the need to improve current calculation methods by accounting for the influence of pile base geometry on its bearing capacity.*
Key words: *bored micropile, field testing, bearing capacity, micropile behavior, static loading, base enlargement.*

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1. INTRODUCTION

The density of modern construction is increasing, making construction workers work in increasingly difficult conditions, often on sites with unsuitable soils. These soils are characterized by low strength, heterogeneity, and high water saturation, which makes foundation design much more difficult. In these cases, traditional types of foundations often prove to be inefficient or technologically unjustified. That is why one of the most common solutions is the use of piles that can transfer loads to deeper, more stable soil layers. Under these conditions, bored micropiles with base enlargement are particularly relevant, as they combine compact dimensions with increased bearing capacity, providing a reliable foundation for the construction of buildings even in difficult areas.

Micropiles are reinforced concrete piles with a round, rectangular or trapezoidal cross-sectional area of up to 300 square centimeters. Their design allows them to perform work in difficult conditions: in dense urban areas, under existing buildings, or in places with limited access. Among their advantages are lower vibrations during installation, flexibility in placement, and the ability to work in weak or heterogeneous soils. Additionally, the formation of a base enlargement of the pile significantly increases its efficiency, allowing for an increase in support area and load-bearing capacity.

The performance of bored piles cannot be assessed exclusively from the perspective of geometric characteristics. The main problem in designing bored piles is the complex behavior of soil, which differs significantly from the properties of traditional building materials. It is important to consider that soil does not have elastic properties. Unlike steel or concrete, which have a defined relationship between stress and strain and are able to partially or completely recover their original state after the load is removed, soil behaves as a plastic, irreversible medium. After loading, the structure of the soil changes and it becomes compacted, which results in incomplete restoration of its initial properties.

This aspect is particularly important when calculating the bearing capacity of piles, since soil settlement should be considered not only as a temporary displacement, but as a change in physical state, which can become critical when the limit loads are exceeded. Accordingly, even minor errors in determining the properties of the soil base can lead to an underestimation of the risk of subsidence, tilting, or structural failure.

Another important characteristic is the nonlinear behavior of soil, which means that deformations are not proportional to the applied load. At low loads, the soil can remain practically unchanged, but after reaching a certain threshold, even a slight increase in load causes a significant increase in settlement. The nonlinearity threshold is determined by the type of soil, its degree of compaction, moisture, and the presence of organic impurities.

Soil moisture is a key factor affecting its physical and mechanical characteristics. Changes in water saturation lead to significant changes in soil shear strength and friction coefficient. For example, dry loam is characterized by relatively high adhesion and internal friction, but when saturated with water, it loses stability, acquires plastic properties, and is easily deformed. In addition, saturated soil creates additional hydrostatic pressure that counteracts the embedment of the pile. Thus, the mechanical behavior of the soil largely depends on its moisture content, which complicates the engineering design process.

The pile interacts with the soil in two main ways: through the lateral surface, through friction and adhesion with the environment, and through the lower surface (heel), through direct resistance to soil compression. The resistance along the lateral surface depends on a number of factors, including soil type, pile surface roughness, pile material, and level of moisture. For example, in dry sands, significant friction can be generated, while in wet loams it can be practically absent. Another important factor is the phenomenon of soil creep, which consists of gradual deformation under prolonged load without further increase in force, which reduces the effectiveness of resistance along the lateral surface. Resistance under the heel is no less complex, as all the force is transmitted vertically, and its value is determined by the compressive strength of the soil. The use of base enlargement of the pile significantly increases the area of contact with the soil, which reduces the load on the foundation and allows for the efficient use of soils with relatively low strength. At the same time, this creates potential risks associated with uneven compaction, localized areas of loss of stability, and heterogeneity of the soil mass, which can lead to unpredictable pile behavior.

The current state of research on bored piles with enlarged bases is characterized by the active development of experimental and numerical methods for analyzing their bearing capacity. Ukrainian scientists [1–3] have made a significant contribution to this field, investigating the influence of enlargements, soil structure, and geometric characteristics on pile performance. Experimental results indicate that the actual bearing capacity of such piles often exceeds the calculated capacity by 20–50%, pointing to the imperfection of current regulatory methods. Numerical modeling using PLAXIS 3D and ANSYS confirms the importance of considering the spatial interaction of the “pile-soil” system and the geometric parameters of the enlargements. Foreign studies [4, 5] show that increasing the number and diameter of enlargements significantly enhances soil resistance and reduces settlement. At the same time, there is a need to create improved design models that would account for the real physical and mechanical properties of dispersive soils and ensure greater accuracy in predicting the behavior of micropiles in complex engineering and geological conditions.

Thus, the design of pile foundations requires a comprehensive approach that involves not only analytical calculations but also consideration of real engineering and geological conditions, such as geological structure, degree of water saturation, and the technological features of drilling and concreting. Particular attention should be paid to innovative structural solutions, such as bored micropiles with base enlargement, for which traditional methods may be insufficient. For the practical verification of the effectiveness of these structures, it is advisable to conduct full-scale field tests in real geological conditions. This allows not only for the confirmation of theoretical assumptions but also for the optimization of design solutions, increasing the reliability of the structure, and rational resource utilization.

2. METHODOLOGY OF RESEARCH

2.1. Peculiarities of the test pile arrangement

The test site was a plot for the construction of a civil residential two-story building located at: Lviv region, Hriada village, Bandery Street, 2. Micropile testing was carried out directly within the boundaries of the designed foundation, which ensured that the studied conditions closely approximated real operating conditions.

The bored micropiles were manufactured in pre-drilled boreholes with a diameter of 200 mm using the mechanical drilling method. The pile length was 3.7 m, and a base enlargement with a diameter of 350 mm was created using a special manual expander. The structure of the test pile is similar to the design of the four anchor piles.

The piles were reinforced using a spatial reinforcement cage formed from two rods of 12 mm diameter reinforcing steel, in accordance with the requirements of [6]. The main pile material was B25 concrete (C20/25). The concrete mixture was placed by the method of continuous supply through a tremie pipe until the borehole was completely filled, taking into account the requirements to avoid segregation of the mixture and the formation of voids. The number of piles required to ensure the normative bearing capacity of the foundations was refined based on the results of full-scale testing of micropiles with static compression loading in accordance with the requirements of [7]. In accordance with the geological conditions, the piles were installed within a single soil layer (EGE-3).

2.2. Engineering and Geological Conditions of the Test Site

Geological investigations at the site were carried out by mechanical drilling of a borehole with a depth 6 m and a diameter of 89 mm. Soil samples were collected using a driven core sampler of a similar diameter. Monoliths of cohesive soils were extracted for further laboratory investigations.

The conditions of soil occurrence, their composition, and physical and mechanical characteristics were studied in laboratory conditions in accordance with current regulatory documents [8–10]. Laboratory tests were conducted in the certified laboratory of PrJSC «UkrZahidEnergoProekt». Based on the results of laboratory investigations and archival materials, three engineering-geological elements (EGE) were identified according to the requirements of [11] (Table 1).

2.3. TEST BENCH

The tests were carried out in compliance with the requirements of [12–14]. The test bench for conducting static compression tests of micropiles was assembled directly on the construction site. Four anchor piles (Figures 1, 2), constructed using the same technology as the test pile, were used to resist the reactive force. They were positioned symmetrically outside the zone of influence of the pile being tested, which excluded their mutual influence during the loading process.

Table 1

Engineering and geological characteristics of the object of research

Number and Name of EGE	Layer Thickness, *m*	Normative Soil Cohesion, kPa	Normative Angle of Internal Friction, deg	Normative Modulus of Deformation, MPa	Calculated Soil Cohesion, кПа	Calculated Angle of Internal Friction, deg	Calculated Soil Cohesion, tf/m^3
1. Topsoil-vegetation layer – humified loamy soil	0.5–0.6	-	-	-	-	-	-
2. Highly peaty loamy soil, soft-flowing plastic, locally silty, with interlayers and pockets of well-decomposed peat, water-saturated	2.7–3.0	10	6	1.5	10	6	11.7
3. Sandy loam, plastic, sandy, with limestone gravel inclusions up to 10%	2.4	14	25	19	2.02	25	20.2

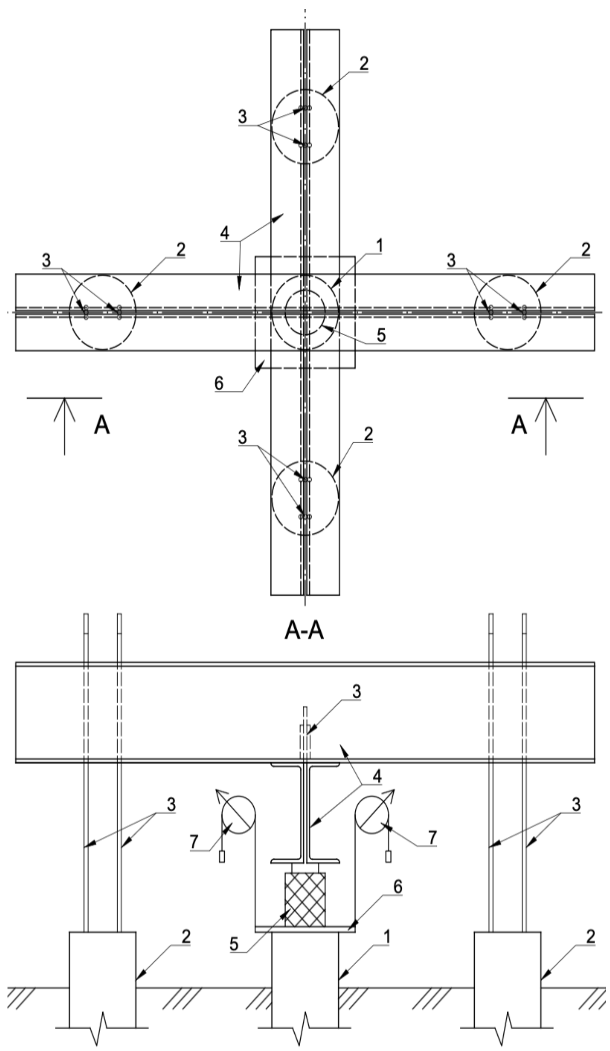

Figure 1. Diagram of the test bench 1 – test pile; 2 – anchor piles; 3 – reinforcing bars; 4 – distribution beams; 5 – hydraulic jack; 6 – base plate; 7 – Aistov's deflectometers 6PAO

Figure 2. General view of the test bench

The reactive load was transferred through a rigid metal structure made in the form of a frame system of paired steel channels No. 24. A hydraulic jack connected to a manual pumping station was installed on the head of the test pile, which ensured the gradual application of a vertical load in a controlled manner. Before installing the equipment, the upper part of the pile was cleaned of soil and cut to the design elevation to ensure reliable contact with the loading system.

The test site arrangement included leveling and compacting the soil around the pile to provide a stable base for the equipment mounting. All components of the test rig were easily accessible for installation and measurement operations. Vertical displacements were measured using Aistov deflectometers. The devices were mounted on an independent measuring frame that was not structurally connected to the main test system. The frame rested on separate brackets rigidly anchored in the soil, positioned at a safe distance from the pile, which allowed minimizing the impact of deformations and external factors on the accuracy of the settlement measurements.

2.4. Pile test methodology

Before starting the test, all measuring devices were calibrated and indicators were adjusted to zero readings. The test pile was tested using the static loading method in accordance with the requirements of [15]. The testing process was carried out in through the application of a stepwise load at fixed time intervals and control of the stability of movements at each stage. The load was set gradually – with an increase of 10 % of the calculated value of the pile bearing capacity. Since the normative bearing capacity of the pile is 38 kN, a loading step of 4 kN was adopted.

Each load step was maintained for the time required to stabilize the settlement, or at least 30 minutes. The fixation of vertical displacements of the pile was carried out with an accuracy of 0.01 mm. The limit settlement in accordance with [16] (Appendix A) was determined as 15 mm for civil multi-story buildings with reinforced concrete frames and monolithic floors.

After reaching the limit load, sequential unloading was performed and the value of elastic recovery was recorded. All load values and corresponding displacements were systematically recorded for further graphical analysis. Based on the test results, the load-unload curve was plotted and the actual bearing capacity of the pile was determined in accordance with the criteria established by the relevant regulatory documents.

3. TEST RESULTS

During the experimental study, it was established that the bored micropile can withstand a load of 72 kN at the moment of reaching the limit deformation of the base. Settlement during the test occurred evenly, without manifestations of progressive deformations or a sudden increase in vertical displacements (Fig. 3).

After the load was removed, a significant elastic rebound was recorded, indicating proper contact of the pile with the soil and sufficient stiffness of the pile-base system. The obtained load curve has a typical shape with a clearly defined initial deformation section followed by a transition to a conditionally smooth settlement. Partial elastic recovery was recorded during unloading. The residual deformation was about 9 mm.

According to the requirements of [17], the allowable load is determined taking into account the reliability factor γ=1.2. hus, the allowable load on the pile is calculated as:

$$F_d=F_u/\gamma=72kN/1,2=60kN$$

The actual bearing capacity of the test pile is 60 kN, which is 57% higher than the calculated normative value of 38 kN, calculated in accordance with [17]. This indicates a significant margin of safety in the pile design and the effectiveness of the adopted solution for base enlargement. The results obtained can be taken into account when refining the design solution and optimizing the number of piles in the foundation of the structure.

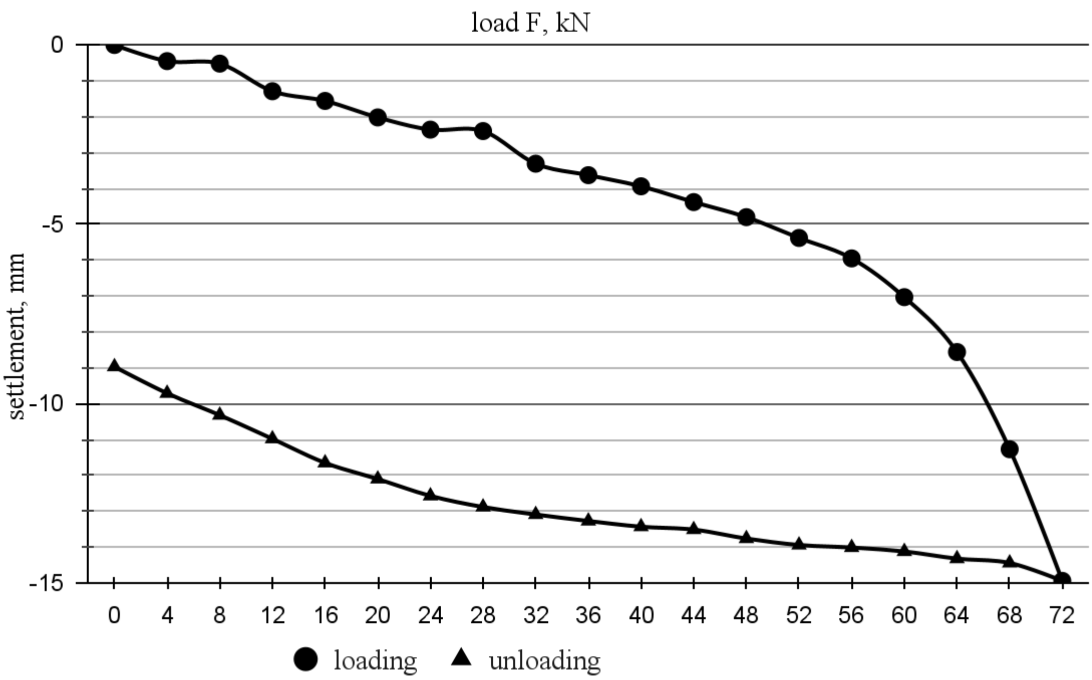

Figure 3. Graph of dependence of vertical settlements of the tested pile under loading and unloading

4. CONCLUSIONS

1. The conducted full-scale tests of the bored micropile with base enlargement, performed in a pre-drilled borehole under the action of a vertical static load, confirmed a sufficient level of its bearing capacity and the permissibility of vertical movements at a design load of 38 kN.

2. The recorded ultimate load of 72 kN, which almost doubles the normative value, indicates a significant margin of safety and the effectiveness of the adopted engineering and design solutions in the design of the pile with base enlargement.

3. The test results confirmed the feasibility of using bored micropiles of this design for the foundations of a two-story civil building, taking into account the specified engineering and geological conditions.

4. A significant excess of the actual bearing capacity of the pile over the calculated value indicates the need for further research into the performance in soils of different types, namely to improve the accuracy of predicting the pile performance in specific soil conditions.

References

1. Korniyenko M. V., Karpenko D. A. (2008) Bearing capacity of bored piles with enlargement in loess soils based on static test results. Foundations and Substructures: Interdepartmental Scientific and Technical Collection, no. 31, pp. 54–63.
2. Demchyna B., Kunanets Yu., Volosetskyi N. (2014) Measurement of forces under the pile base using a special measuring plate. Visnyk of Lviv National Agrarian University. Architecture and Agricultural Construction, no. 15, pp. 40–45.
3. Boiko I. P., Pidlutskyi I. P. (2012) Investigation of pile installation in a foundation of different lengths. Collection of Scientific Works of Poltava National Technical University named after Yuri Kondratyuk. Series: Industrial Engineering, Construction, issue 4 (2), pp. 42–48.
4. Nasr A. M., Azzam W. R., Harran I. S. (2023) Geometrical influence of an under-reamed pile in clay under compressive load: a numerical study. Advances in Geological and Geotechnical Engineering Research, 5 (1), pp. 1–9. https://doi.org/10.30564/agger.v5i1.5276
5. Kazimierz Józefiak, Artur Zbiciak, Maciej Maślakowski, Tomasz Piotrowski (2015) Numerical modeling and analysis of the bearing capacity of a pile foundation. Procedia Engineering, vol. 111, pp. 356–363. https://doi.org/10.1016/j.proeng.2015.07.101
6. DSTU B V.2.6-156:2010. Buildings and structures. Concrete and reinforced concrete structures made of heavy concrete. Design rules.
7. DSTU-N B V.2.1-28:2013. Guidelines for performing earthworks, construction of foundations and substructures (SNiP 3.02.01-87, MOD).
8. DBN A.2.1-1-2008. Surveying, design, and territorial activity. Engineering surveys for construction.
9. DSTU B V.2.1-17:2009. Foundations and substructures of buildings and structures. Soils. Methods for laboratory determination of physical properties.
10. DBN V.2.1-10:2018. Foundations and substructures of buildings and structures. General provisions.
11. DSTU B V.2.1-5-96. Foundations and substructures of buildings and structures. Soils. Methods of statistical processing of test results.
12. DSTU B V.2.1-27:2010. Foundations and substructures of buildings and structures. Piles. Determination of bearing capacity based on field test results.
13. DSTU B V.2.1-1-95. Foundations and substructures of buildings and structures. Soils. Method of field pile testing.
14. Eurocode 7: EN 1997-1:2004 /AC/. Geotechnical design – Part 1: General rules (together with United Kingdom National Application Document). 88 p.
15. DSTU ISO 22477-1:2015. Geotechnical investigation and testing. Testing of piles. Part 1: Static load testing of piles.
16. DBN V.2.1-10:2018. Foundations and substructures of buildings and structures. General provisions.
17. DBN V.2.1-10:2009. Construction facilities and industrial construction products. Foundations and substructures of buildings and structures. Foundations and substructures. General design provisions.

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НАТУРНЕ ВИПРОБУВАННЯ БУРОВОЇ БЕТОННОЇ МІКРОПАЛІ З РОЗШИРЕННЯМ У ДИСПЕРСНИХ ГРУНТАХ

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Резюме. *Наведено результати натурних випробувань бурової мікропалі з нижнім розширенням, влаштованої в межах фундаменту двоповерхової цивільної будівлі на території Львівської області. Показано, що застосування розширення діаметром 350 мм у нижній частині палі дає змогу суттєво підвищити її несучу здатність. Проведено інженерно-геологічне обстеження ділянки, в межах якої виділено три інженерно-геологічні елементи, що охоплюють слабкі водонасичені суглинки та супіски. Отримано експериментальні дані про поведінку палі під дією статичного втискувального навантаження до 72 кН, що майже вдвічі перевищує розрахункове нормативне значення 38 кН. Випробування виконано безпосередньо в межах реального фундаменту споруди, що забезпечило достовірність і практичну цінність отриманих результатів. Методика випробування передбачала поетапне прикладання навантаження з одночасною реєстрацією вертикальних переміщень за допомогою високоточних вимірювальних приладів. За результатами випробування побудовано криву «навантаження–розвантаження», що має типовий характер зі стадіями початкової деформації, стабілізованого осідання та пружного відновлення. Показано, що система «паля–основа» працює без ознак прогресуючих деформацій і демонструє значне пружне відновлення після розвантаження. Розрахунок допустимого навантаження з урахуванням коефіцієнта надійності (γ=1.2) дозволив визначити фактичну несучу здатність палі на рівні 60 кН, що на 57 % перевищує проектне значення. Звідси випливає, що конструкція палі з нижнім розширенням є ефективною для заданих інженерно-геологічних умов та забезпечує надійність фундаменту за менших витрат. Отримані результати підтверджують ефективність застосування бурових мікропаль із нижнім розширенням у малоповерховому будівництві та вказують на необхідність удосконалення чинних методик розрахунку з урахуванням впливу геометрії основи палі на її несучу здатність.*

Ключові слова: *бурова мікропаля, натурне випробування, несуча здатність, робота мікропалі, статичне навантаження, нижнє розширення.*

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