ABSTRACT

of the dissertation by Nurzhan Shanshabayev on the title:
"Development of pyramidal-prismatic pile structures and evaluation of their load-bearing capacity for stand-alone foundations of hydraulic structures" for the degree of Doctor of Philosophy (PhD) in the field of 8D074 – Water Resources, Educational Program 8D07411 – Hydraulic Engineering and Structures

Relevance of the Research Title. In most cases, hydraulic structures (aqueducts, debris flow channels, culverts, pipelines, retaining walls, pumping stations, etc.) are constructed and operated in complex engineering-geological, hydrogeological, and topographic conditions. These include structurally unstable soils, areas with high groundwater levels, slopes, ravines, riverbeds, and regions prone to landslides and flooding. Therefore, the stability and durability of these structures largely depend on the strength and reliability of their foundations. Traditionally, constructing hydraulic structures under these conditions is associated with increased labor, material, and financial costs, a significant portion of which is related to foundation work. Consequently, it is essential in hydraulic engineering to use foundation structures that are both effective in load-bearing capacity and cost-efficient. Geotechnical structures such as driven pile foundations are typically considered efficient solutions in this context. In certain situations, they may represent the only rational choice for structures built on soils with insufficient load resistance.

Pile foundations are a type of foundation used in hydraulic structures. In hydraulic construction practice, driven pile foundations of various longitudinal shapes are primarily used. Among these, prismatic and pyramidal piles are the most common. Pyramidal piles have 1.35 to 2.5 times higher load-bearing capacity than prismatic piles, depending on the angle of their lateral faces. However, the energy consumption of pile-driving hammers for installing pyramidal piles is 2 to 3 times higher, leading to increased driving duration and equipment wear. Consequently, while prismatic piles are less efficient in terms of load-bearing capacity, they have significant advantages in energy efficiency and driving time. To leverage the advantages of both prismatic and pyramidal piles, a new pile design is proposed, featuring a shaft with both prismatic and pyramidal sections. Specifically, the upper part of the pile shaft should be pyramidal, while the lower part should be prismatic. This geometric combination within the pile shaft will effectively compact weak surface soils, which are typically loosened during the driving of prismatic piles.

Currently, such foundation structures are not available in pile geotechnics or hydraulic construction, highlighting the relevance of their development and the study of their driving characteristics and performance under static loads.

Research Objective. The aim of this research is to develop pyramid-prismatic pile designs and assess their load-bearing capacity under static loads.

Based on this objective, the **research tasks** are as follows:

- to study the characteristics of soil deformation during the driving of pyramid-prismatic piles;
- to investigate the behavior of pyramid-prismatic piles under compressive, tensile, and horizontal static loads;

- to assess the impact of soil type and the dimensions of the pyramidal section on driving energy and load-bearing capacity;

- to develop recommendations for using pyramid-prismatic piles in the foundations of hydraulic structures;

- to create a nomenclature and working drawings for the factory production of these piles.

Research Object. The object of the research is driven reinforced concrete pyramid-prismatic piles.

Research Subject. The research focuses on soil deformability, the drivability and energy consumption of pyramid-prismatic piles, and their resistance to static loads.

Scientific Novelty:

- a pyramid-prismatic pile design has been developed (protected by RK Patent No. 4521, dated December 5, 2018);

- the patterns of deformation in the soil zone during the driving of pyramid-prismatic piles have been identified;

- the drivability, energy consumption, and load-bearing capacity of experimental piles have been evaluated and compared with prismatic and pyramidal piles;

- the influence of the length of the pyramidal section and the upper cross-sectional dimensions on drivability, driving energy, and load-bearing capacity has been determined;

- methods for determining the load-bearing capacity of pyramid-prismatic piles under compressive, tensile, and horizontal loads have been developed, along with recommendations for calculating horizontal load resistance;

- a nomenclature and working drawings for pyramid-prismatic piles, along with guidelines for their application in hydraulic structures, have been created.

The practical significance of the work. The results of the experimental studies, along with the developed methods and recommendations, are included in R-1-24 "Recommendations for the design and installation of foundations made of pyramidal-prismatic piles." The application of these recommendations will enable efficient design of foundations using pyramidal-prismatic piles for hydraulic structures, thereby facilitating their use in hydraulic engineering practice. The increased bearing capacity of pyramidal-prismatic piles compared to prismatic piles will allow for a reduction in the consumption of reinforcement and concrete in hydraulic construction by decreasing the number of piles or their length in the foundations of buildings and hydraulic structures.

Technical documentation for manufacturing experimental piles has been developed and approved:

- Album 1: Working Drawings for Solid Reinforced Concrete Pyramid-Prismatic Piles with Non-Prestressed Reinforcement;

- Album 2: Working Drawings for Solid Reinforced Concrete Pyramid-Prismatic Piles with Prestressed Reinforcement.

The application of these documents will enable the production of pyramid-prismatic piles in domestic enterprises for use in hydraulic construction projects.

Research Methodology. The research employed the following principles and methodologies: the principles and conditions for modeling piles, their installation process, and performance under load; methods for conducting laboratory and field experiments; techniques for calculating the bearing capacity of piles; methods for computer processing and graphical representation of experimental research results; regulations for developing nomenclature and working drawings, as well as the software “TPP-20.24”; methodology for creating a bearing capacity calculation program for piles; and cost estimation based on the software package ABC.

Key Defended Provisions:

- results of laboratory studies on soil deformation patterns during pile driving;
- results of laboratory and field studies on pile drivability and energy consumption;
- results of laboratory and field studies on pile resistance under various static loads;
- methods for determining pile load-bearing capacity under compressive and tensile loads, and recommendations for horizontal load calculations;
- working drawings and application guidelines for hydraulic construction projects.

The relationship of dissertation work with research and grant projects:

- this work was carried out as part of the implementation of the grant for program-specific financing BR24992867 – "Development of resource-saving technologies for the development and management of water management and processing industry in Kazakhstan, creation of an innovative engineering center" of the Science Committee of the Ministry of Internal Affairs of the Republic of Kazakhstan.

Testing of Results. The main findings were presented and discussed at conferences and seminars, including:

- International Conference on "Deep Foundation and Geotechnical Issues of Territories" (Perm National Research Polytechnic University, Perm, 2021);
- XIII International Scientific Conference of Young Scientists on "Innovative Development and the Relevance of Science in Modern Kazakhstan" (M.Kh. Dulaty Taraz Regional University, Taraz, 2019).
- Zhambul Branch of the RSE “Kazvodkhoz” (Taraz, 2019); LLP “KazGiproVodKhoz Design Institute” (Almaty, 2019); D.A. Kunayev BAK Branch (Talgar, 2019); PUE “Geoservice” (Minsk, 2021); South Kazakhstan Branch of JSC “KazNIISA” (Taraz, 2019-2020).
- M.Kh. Dulaty Taraz Regional University (annually); Brest State Technical University (2018-2021); Belarusian National Technical University (2021).

Publications. The research results have been published in:

- 7 articles published in scientific journals included in the list recommended by the Committee for Quality Assurance in Science and Higher Education of the Ministry of Science and Higher Education of the Republic of Kazakhstan;
- 2 articles published in national scientific journals;
- 4 articles published in conference proceedings;

- 3 articles published in international and domestic journals included in the Scopus and Clarivate Analytics databases ("Periodica Polytechnica Civil Engineering", "Acta Montanistica Slovaca" and "News of the National Academy of Sciences of the Republic of Kazakhstan. Series of Geology and Technical Sciences").
- 2 utility model patents obtained in the Republic of Kazakhstan: No. 4521 and No. 4386.

The structure and scope of the thesis. The thesis consists of an introduction, 4 chapters, conclusions, a list of used sources from 126 titles (including 88 foreign ones), and appendices. The work is presented on 193 pages of typewritten text, contains 64 figures, 48 tables.

The main content of the work. The dissertation research is aimed at an experimental study of the submersibility and energy intensity of hammering, as well as the resistance of pyramidal-prismatic piles when exposed to vertical, horizontal and pulling loads for the foundations of buildings and structures for hydraulic engineering purposes.

The introduction of the thesis substantiates the relevance of the chosen scientific topic, reflecting its importance for the current state and prospects of development of the field under study. The goals and objectives of the research are clearly formulated, the object and subject of the research are defined, which makes it possible to set a scientific direction and outline the boundaries of the work being carried out. Special attention is paid to scientific novelty, which consists in obtaining new theoretical provisions, clarifying previously known patterns and developing methodological approaches that contribute to the development of scientific knowledge and practice. The main provisions submitted for defense are highlighted, reflecting both theoretical results and applied aspects.

The text of the introduction describes the methodology and research methods, including analytical, experimental and computational approaches, as well as the rationale for their choice in terms of reliability and reproducibility of the results.

The practical significance of the work is emphasized, which is expressed in the possibility of applying the results obtained in solving actual engineering and production tasks, as well as in their use to improve existing technologies and regulatory and methodological framework.

Additionally, information about the author's publications is provided, confirming the approbation of the results obtained in scientific publications and at conferences of various levels. The introduction ends with a description of the structure and scope of the dissertation, which indicates the number of chapters, sections, illustrative material and appendices, which gives a complete picture of the composition and logic of the presentation of the work.

The first chapter presents a comprehensive study of the current state of scientific papers on the design and application of pile foundations in hydraulic engineering. Constructive solutions of foundation systems of hydraulic structures of various types (dams, locks, water intake and coastal protection structures) are considered.

Special attention is paid to the generalization and systematization of the results of domestic and foreign studies related to the operation of piles and pile fields under hydraulic structures. A comparative analysis of traditional cylindrical and prismatic piles with new design solutions, including pyramidal-prismatic piles, which provide increased load-bearing capacity due to the increased sole area and improved lateral surface performance in water-saturated soils.

Based on the identified scientific and practical trends, the relevance of the use of pyramidal-prismatic piles as part of pile foundations of hydraulic structures is substantiated. The main research objectives are formulated, aimed at clarifying the mechanisms of pile operation in difficult hydrogeological conditions, developing methods for calculating load-bearing capacity and sediment, as well as experimental and theoretical evaluation of the effectiveness of new types of pile structures.

Conclusions from the first chapter:

The analysis of research and experience in the use of pile structures for the construction of hydraulic structures allows us to draw the following main conclusions:

1. Drilling piles in hydraulic engineering are used as anti-filtration curtains of dams, to block riverbeds, ensure the safety and stability of slopes, banks, slopes, etc. In addition, they are successfully used in the construction of the foundations of hydraulic structures. The diameter of the piles used is 0.6-1.0 m, and the depth is up to 40 m. In recent years, borehole piles have been actively used as an anti-filtration curtain for dams, as well as for the construction of protective structures for hydraulic engineering facilities. Such piles are arranged with a diameter of up to 1.20 m, and a depth of 40 m or more.

2. Driven piles are widely used in hydraulic engineering, which are characterized by such qualities as cost-effectiveness, adaptability, quickness and reliability. The peculiarities of the work of various types of driven piles (prismatic, wedge-shaped, conical) and pile foundations from them for the construction of a number of hydraulic structures (channel channels, aqueducts, sea and river piers, embankments, fencing, shore-strengthening structures, etc.) are revealed. Methods for calculating the parameters of immersion, deformability, stability and bearing capacity of piles and pile foundations have been developed and used, which take into account the patterns of their joint work with hydraulic structures.

3. Along with other pile structures, sheet piles made of various materials, including composite ones, are effectively used in hydraulic engineering. The most commonly used steel sheet piles are of different profiles and lengths. A number of new tongue-and-groove piles have been developed to ensure high load-bearing capacity and reliability of structures under construction in the form of berths, embankment fences, slope anchors, etc.

4. Of the driven piles in the field of hydraulic engineering, prismatic piles are used to a greater extent than piles with an inclined side surface. Both ceramic and inclined side surface piles have their own work features and advantages. Piles with an inclined side surface have a shorter length compared to prismatic piles, are more efficient in terms of bearing capacity, and are less efficient in terms of the energy required by hammers to sink them. Prismatic piles have a long length, provide high accuracy of immersion in the ground, as well as reaching the lower ends of solid soils at great depths.

5. Based on the consideration of geometric parameters that determine the predominant features of piles with an inclined side surface of the trunk and traditional prismatic piles, a driven pile with a pyramidal-prismatic trunk shape is proposed. The relevance of conducting experimental and theoretical research by the dissertation researcher on the process of driving pyramidal-prismatic piles and the features of their operation under the action of static loads is substantiated.

The second chapter of the dissertation provides a description of the test equipment used, its design features, principles of operation and operating conditions during research are disclosed. The parameters of the experimental pile models are considered in detail, including their geometric dimensions, cross-sectional shape, reinforcement and materials used. The process of manufacturing reinforced concrete piles in laboratory conditions is described, starting with the preparation of the reinforcing frame and the selection of the composition of the concrete mixture before laying the mixture in the formwork, the modes of compaction and subsequent hardening of concrete.

Special attention is paid to concrete strength tests, which were performed according to standard methods for determining cubic strength in order to verify compliance with design characteristics. The chapter also contains the physico-mechanical characteristics of soils obtained on the basis of laboratory studies and field tests: determination of granulometric composition, humidity, density, angle of internal friction, adhesion and modulus of deformation.

In addition, the methodology for conducting both laboratory experiments and field tests of pyramidal-prismatic piles is described in detail. The conditions of setting up experiments, the procedure for mounting and loading piles, methods for fixing deformations and sediments, as well as the principles of processing experimental data are considered. Thus, the second chapter forms the basis for a comprehensive analysis of the work of the piles under study and serves as a basis for comparing laboratory and field results.

The third chapter presents the results of comprehensive experimental studies on the operation of pyramidal-prismatic piles in comparison with traditional prismatic and fully pyramidal piles. The main attention is paid to identifying the features of the formation and modification of the deformed zone of the soil mass at various stages of interaction of piles with the base – during their immersion and subsequent pulling out. Additionally, the issues of assessing the influence of the geometric shape of piles with widenings on the technological parameters of immersion, as well as on the energy intensity of driving, which is important for optimizing construction processes, are considered.

A special place in research is occupied by determining the bearing capacity of piles under the action of vertical crushing loads, horizontal forces and static pulling effects, which makes it possible to comprehensively assess the operational reliability of structures in real engineering and geological conditions. The work also focuses on the analysis of the influence of the physico-mechanical characteristics of soils (sandy, clay, water-saturated, etc.) on the performance of piles. A study has been conducted on the dependence of the submersibility, energy intensity of the hammering and load-bearing capacity on the design parameters of the pyramidal part of pyramidal-prismatic piles, including the angle of its opening, height and the ratio of dimensions to the total length of the pile.

The results obtained make it possible to establish patterns of interaction of various types of piles with the soil base, as well as to give practical recommendations on the rational design and use of pyramidal-prismatic piles in the construction of Hydraulic Structures.

Conclusions on the third chapter:

1. The driving of experimental piles is accompanied by significant deformation of the soil compared to prismatic and pyramidal piles. The width of the deformed soil zone around the experimental piles is 5.0-32.0% greater than around the compared piles. The optimal distances between piles, depending on the size of their pyramidal section, should be set from 3d to 4d.

2. The energy cost of driving experimental piles with a pyramidal section length of 1-4 m and the size of its upper section from 30 × 30 cm to 50× 50 cm is 1.05-2.48 times higher than when driving a prismatic pile with a cross-sectional size of 20 × 20 cm. Depending on the length and size of the upper section of the pyramidal section, as well as the type of soil, the energy costs of submerging the pyramidal-prismatic pile (hereinafter PPP) are 3.0-59.0% less than the similar costs of driving a prismatic pile with a cross-section size of 30×30 cm. Depending on the type of soil and the length of the pyramid section, the energy costs for sinking experimental piles are 9.0 - 49.0% lower than for driving a pyramid pile.

3. With an increase in the length of the pyramidal section of the experimental piles from 1 to 4 m and the size of the upper section of their pyramidal section by 1.33-1.67 times, the energy costs for their driving increase by 1.24-1.74 times and 1.07-1.42 times, respectively. Driving piles into clay soil is accompanied by higher energy costs than into sandy soil (1.72-2.55 times).

4. An increase in the length of the pyramidal section of the experimental piles from 1 to 4 m leads to an increase in the specific energy costs of driving them by 1.25-1.71 times compared with a prismatic pile with a cross-section size of 20×20 cm, as well as to a decrease in similar costs by 1.38-27.80% compared with a pyramidal pile and a prismatic pile with the cross-section dimensions are 30×30 cm.

5. An increase in the size of the upper section of the pyramidal section of the PPP by 1.33-1.67 times (with a length of the pyramidal section of 1 and 2 m) causes an increase in their specific energy intensity of clogging by 1.24-1.32 times compared with a prismatic pile with a cross-section size of 20×20 cm, as well as a slight decrease in such costs (by 1.1-4.8%) compared to a pyramidal pile and a prismatic pile with a cross-section size of 30×30 cm.

6. The higher the specific energy intensity of driving experimental piles, the longer the length of their pyramidal section (1.04-1.33 times). The specific energy intensity of driving experimental piles into clay soil is higher than when driving them into sandy soil (1.74 to 2.60 times).

7. Under the action of a static pressure load, the bearing capacity of the PPP is higher than the bearing capacity of prismatic piles with cross-section sizes of 20×20 cm and 30×30 cm, respectively, by 1.23-2.80 times and 1.03-1.65 times. The bearing capacity of the PPP is lower by 6.42-24.77% compared to the pyramidal pile. With an

increase in the length of the pyramidal section of the PPP and the size of the cross-section of the top of their pyramidal section by 1.33-1.67 times, the bearing capacity of the experimental piles increases by 1.24-3.52 times. The bearing capacity of PPP under the action of an indentation load in clay soil is 1.03-1.62 times higher than in sandy soil.

8. The specific load-bearing capacity of the PPP is 1.15-2.40 times and 1.42-2.60 times higher than the specific load-bearing capacity of prismatic piles with cross-section sizes of 20×20 cm and 30×30 cm, respectively. The specific bearing capacity of the PPP is lower by 3.90-41.0% compared to the pyramidal pile. An increase in the length of the pyramidal section of the PPP and the size of the section of the top of their pyramidal section is accompanied by an increase in the specific load-bearing capacity of the piles by 1.11-1.32 times and 1.15-1.64 times, respectively.

9. The resistance of the PPP to static horizontal load is 1.13-2.27 times higher than that of a prismatic pile with a cross-section size of 20×20 cm and is 2.0-54.0% and 7.0-49.0% lower, respectively, than that of a prismatic pile with a cross-section size of 30×30 cm and a pyramidal pile. With an increase in the length of the pyramidal section 2-4 times and the size of the cross-section of the top of their pyramidal section by 1.33-1.67 times, the resistance of experimental piles to horizontal loading increases by 1.09-1.71 times and 1.18-1.69 times, respectively. The resistance of PPP to horizontal load in clay soil is 1.25-1.73 times greater than in sandy soil.

10. The bearing capacity of the PPP to the pulling load is 1.04-1.78 times higher than that of a prismatic pile with a cross-section size of 20×20 cm and less, respectively, by 6.0-45.0% and 8.0-49.0% than the bearing capacity of a prismatic pile with a cross-section size of 30×30 cm and a pyramidal pile. With an increase in the length of the pyramidal section by 2-4 times and the size of the cross-section of the top of their pyramidal section by 1.33-1.67 times, the bearing capacity of the experimental piles increases by 1.09-1.33 times and 1.15-1.41 times, respectively. The bearing capacity of PPP under the action of a pulling load in sandy soil is 1.25-1.73 times greater than in clay soil.

The fourth chapter of the thesis presents the methods developed by the author for calculating the bearing capacity of pyramidal-prismatic piles under the action of various types of static loads. Vertical pressing forces are considered, which take into account the joint resistance of the soil both on the side surface of the piles and on their lower base, as well as horizontal and pulling loads that have a significant impact on the work of piles in the pile foundations of hydraulic structures.

Based on the conducted research, practical recommendations on the use of pyramidal-prismatic piles in the foundation structures of hydraulic engineering facilities are proposed. In particular, reasonable proposals are given to determine the minimum required impact energy of a pile driver to ensure reliable immersion of piles in the ground up to the design mark. Schemes for optimal placement of piles in terms of grillings have also been developed, which makes it possible to efficiently distribute loads and reduce the unevenness of precipitation.

Special attention is paid to the technological aspects of manufacturing pyramidal-prismatic piles. The nomenclature and marking system of piles of various lengths and cross-sections are presented, as well as recommendations for the design of reinforcing frames, taking into account the work of piles on bending, stretching and compression. Examples of working drawings of piles are given, indicating the main parameters: the mass of the products, the consumption of concrete and reinforcing steel for their production.

The final element of the study is a comparative economic assessment of the construction of foundations of hydraulic structures using pyramidal-prismatic piles in comparison with traditional types of pile foundations. The analysis takes into account the cost of manufacturing piles, transportation costs, the complexity of driving them and the total consumption of materials. The data obtained confirmed the economic feasibility of using pyramidal-prismatic piles in a number of engineering and geological conditions, which opens up opportunities for their wider implementation in the Hydraulic Structures.

Conclusions on the fourth chapter:

1. A method has been developed for calculating the bearing capacity of PPP under the action of a static pressure load, based on taking into account the calculated resistances of the soils lying under the lower end of the piles and along their lateral faces. The method takes into account the influence of the longitudinal shape of the trunk of the experimental piles, as well as the type of soil on their resistance. These factors are taken into account using coefficients determined by comparing calculated and experimental data on the bearing capacity of piles. The proposed coefficients are established on the basis of correlations with respect to the length of the pyramidal section of the experimental piles. Based on the method, an applied computer program has been developed that makes it possible to calculate the bearing capacity of experimental piles.

2. Methods for determining the bearing capacity of PPP under the action of horizontal and pulling loads are proposed, which make it possible to assess the resistance of experimental piles relative to the resistance of prismatic and pyramidal piles of the same length. The methods are based on the use of pile efficiency coefficients for horizontal movement of their heads by 10 mm and for pulling out piles, established by the results of experimental studies. To determine these coefficients, correlations were obtained that allow taking into account the size of the pyramidal section of piles and the type of soil into which the piles are driven.

3. Recommendations have been developed to determine the required minimum hammer impact energy for driving experimental piles into homogeneous clay and sandy soils, and recommendations have been proposed for the placement of PPP in terms of foundations of hydraulic structures in the form of single piles, pile bands and pile bushes.

4. A technical and economic assessment of the use of PPP as part of the foundations of pumping station buildings has been carried out. It was found that the construction of a pile foundation made of PPP instead of a slab foundation and a pile foundation made of prismatic piles are more cost-effective. The use of foundations made of PPP reduces the cost of work by 88.25-95.24% compared to a slab

foundation and by 16.78-24.74% compared to a pile foundation made of prismatic piles.

5. Relevant technical and instructional documentation has been developed and published to ensure the industrial production of PPP at domestic enterprises and their use for the construction of hydraulic engineering facilities. The technical documentation includes working drawings of experimental piles with stressed and non-stressed fittings, basic parameters, material consumption and requirements for their manufacture in the factory. The instructional documentation contains issues related to the design, calculation and installation of foundations from PPP for buildings and structures for hydraulic engineering purposes, taking into account the requirements of Eurocode 7.

The appendix describes an algorithm for the operation of an application program that allows calculations of the bearing capacity of pyramidal-prismatic piles on a personal computer under the action of a vertical pressing static load.

Conclusion

Based on the results of theoretical and experimental studies aimed at studying the features of pyramidal-prismatic piles for the foundations of buildings and structures for hydraulic engineering purposes, the following main conclusions can be formulated:

1. The patterns of layered deformation of the soil around pyramidal-prismatic piles during their driving have been experimentally studied. It has been established that the experimental piles are characterized by a cone-shaped deformed soil zone. The minimum distances between the experimental piles (as part of the foundations) have been determined, which vary from 3d to 4d depending on the size of their pyramidal section.

2. Laboratory and field studies have established the specifics of the operation of pyramidal-prismatic piles under the action of static pressing, pulling and horizontal loads. It has been revealed that experimental piles have lower energy consumption and greater resistance to static loads compared to existing traditional piles. Thus, the energy costs for driving experimental piles are 3.0-59.0% and 9.0-49.0% lower, respectively, than for sinking a prismatic pile with a cross-section size of 30×30 cm and a pyramidal pile with a cross-section size of 30×30 cm above and 20×20 cm below. The bearing capacity of pyramidal-prismatic piles under the action of a vertical pressure load is higher than that of prismatic piles with cross-section sizes of 20×20 cm and 30×30 cm, respectively, by 1.23-2.80 times and 1.03-1.65 times. The specific load-bearing capacity of pyramidal-prismatic piles is also 1.15-2.40 times and 1.42-2.60 times higher than that of prismatic piles with cross-section sizes of 20×20 cm and 30×30 cm, respectively. The resistance of the experimental piles to horizontal and pulling loads is 1.13-2.27 and 1.04-1.78 times higher, respectively, compared with a prismatic pile with a cross-section size of 20×20 cm.

3. The influence of the length and size of the upper section of the pyramidal section of the experimental piles on their energy intensity of driving and bearing capacity in homogeneous strata of clay and sandy soils was estimated. An increase in

the length (by 2-4 times) and the size of the upper section (by 1.33-1.67 times) of the pyramidal pile section is accompanied by an increase in: energy costs for driving by 1.07-1.67 times; bearing capacity under the action of an indentation load by 1.24-3.58 times; resistance to horizontal and pulling loads by 1.09-1.71 times and 1.09 times, respectively.

4. An assessment of the effect of the type of soil on the energy intensity of driving and the bearing capacity of the experimental piles was carried out. The energy costs for driving piles, their bearing capacity under the action of an indentation load, as well as the resistance to horizontal load in clay soil are 1.72-2.55 times higher than in sandy soil, 1.03-0.62 times and 1.25-1.73 times, respectively. In sandy soil, the bearing capacity of experimental piles under the action of a pulling load is 1.25-1.73 times greater than in clay soil.

5. A method has been developed for determining the bearing capacity of pyramidal-prismatic piles under the action of a static pressure load, based on taking into account the calculated resistances of the soils lying under the lower end of the piles and along their lateral faces. The method takes into account the influence of the longitudinal shape (length of the pyramidal section) of the trunk of the experimental piles, as well as the type of soil on their resistance. The method is implemented as an application program that allows performing calculations using a PC.

6. Methods for determining the bearing capacity of pyramidal-prismatic piles under the action of horizontal and pulling loads relative to the resistance of single-length prismatic and pyramidal piles are proposed. The methods involve the use of correlations established between experimental piles and specified traditional piles.

7. Recommendations have been developed and published on the use of pyramidal-prismatic piles for the construction of foundations of hydraulic engineering buildings and structures, including provisions for determining the minimum required hammer impact energy for driving experimental piles into homogeneous clay and sandy soils, for optimal placement of piles in terms of foundations, calculation and design of piles and pile foundations from them.

8. An estimated calculation of the construction of pile foundations from pyramidal-prismatic piles was carried out using the example of two pumping station buildings. The calculation results indicate the cost-effectiveness of foundations made from experimental piles in comparison with traditional slab foundations of shallow laying and pile foundations made of prismatic piles. The use of foundations made of pyramidal-prismatic piles reduces the cost of work by 88.25-95.24% compared with a slab foundation and by 16.78-24.74% compared with a pile foundation made of prismatic piles.

9. Albums of working drawings have been developed, including the range of piles, their geometric parameters, reinforcement schemes, assemblies and parts, as well as the consumption of reinforcement and concrete, to ensure the industrial production of experimental piles at domestic enterprises for use in the construction of hydraulic engineering facilities.

The prospects for further research are related to the study of the characteristics of the resistance of pile bushes and pile belt foundations made of pyramidal-prismatic piles under the action of static and seismic loads. In continuation of the dissertation topic, a grant project has been implemented on the title "Development of hammered fibrocrete high-strength pyramidal-prismatic piles" (IRN AR13268763) under the Zhas Galim competition for 2022-2024.

Assessment of the completeness of the solution of the tasks. The tasks set in the thesis have been fully solved on the basis of theoretical and experimental research conducted by the author. The established features of the operation of pyramidal-prismatic piles under static loads, the developed methods for determining their bearing capacity, working drawings and recommendations for the installation of piles form the basis for their effective use in the construction of foundations of hydraulic engineering facilities.

Development of recommendations and initial data on the specific use of the results. The results of the study are recommended for use by design and construction organizations in the construction of buildings and structures for hydraulic engineering purposes.

Assessment of the technical and economic efficiency of the implementation. The main research results are integrated into the regulatory and technical base of leading organizations for the design of buildings and structures, such as SCF KazNIISA JSC, Taraz Arkon LLP, Meken-Zai Taraz LLP, Tabys Zhoba LLP, Expertise of Earthquake-resistant Construction LLP, Taraz-Technoproekt LLP, "AsiaTurProekt", "Erfolg" LLP, "Binom" LLP and "Gimarat Temirbeton" LLP.

Assessment of the technical and economic level of the work performed. The proposed new design in the form of a driven reinforced concrete pyramidal-prismatic pile for the construction of foundations of buildings and structures for hydraulic engineering purposes, compared with traditional piles, can significantly reduce financial and labor costs for the installation of pile foundations.

Appendix. An algorithm is provided for a software application that enables calculations of the load-bearing capacity of pyramid-prismatic piles under vertical compressive static loads on a personal computer.

The following publications are available on the topic of the dissertation research:

1. Пат. 4521 РК. Забивная железобетонная свая / И.И. Бекбасаров, Н.А. Шаншабаев; опубл. 29.11.2019, Бюл. №5. - 2 с;
2. Пат. 4386 РК. Способ определения несущей способности висячей забивной пирамидально-призмаической сваи / И.И. Бекбасаров, Н.А. Шаншабаев; опубл. 23.10.2019, Бюл. №2019/0526.2. - 2 с;
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