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«ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ» РҚБ
«ХАЛЫҚ» ЖҚ

Х А Б А Р Л А Р Ы

ИЗВЕСТИЯ

РОО «НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК РЕСПУБЛИКИ КАЗАХСТАН»
ЧФ «Халық»

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NAS RK is pleased to announce that News of NAS RK. Series of geology and technical sciences scientific journal has been accepted for indexing in the Emerging Sources Citation Index, a new edition of Web of Science. Content in this index is under consideration by Clarivate Analytics to be accepted in the Science Citation Index Expanded, the Social Sciences Citation Index, and the Arts & Humanities Citation Index. The quality and depth of content Web of Science offers to researchers, authors, publishers, and institutions sets it apart from other research databases. The inclusion of News of NAS RK. Series of geology and technical sciences in the Emerging Sources Citation Index demonstrates our dedication to providing the most relevant and influential content of geology and engineering sciences to our community.

Қазақстан Республикасы Ұлттық ғылым академиясы «ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы» ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Webof Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді геология және техникалық ғылымдар бойынша контентке адалдығымызды білдіреді.

НАН РК сообщает, что научный журнал «Известия НАН РК. Серия геологии и технических наук» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Известия НАН РК. Серия геологии и технических наук в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному контенту по геологии и техническим наукам для нашего сообщества.

ЧФ «ХАЛЫҚ»

В 2016 году для развития и улучшения качества жизни казахстанцев был создан частный Благотворительный фонд «Халык». За годы своей деятельности на реализацию благотворительных проектов в областях образования и науки, социальной защиты, культуры, здравоохранения и спорта, Фонд выделил более 45 миллиардов тенге.

Особое внимание Благотворительный фонд «Халык» уделяет образовательным программам, считая это направление одним из ключевых в своей деятельности. Оказывая поддержку отечественному образованию, Фонд вносит свой посильный вклад в развитие качественного образования в Казахстане. Тем самым способствуя росту числа людей, способных менять жизнь в стране к лучшему – профессионалов в различных сферах, потенциальных лидеров и «великих умов». Одной из значимых инициатив фонда «Халык» в образовательной сфере стал проект Ozgeris powered by Halyk Fund – первый в стране бизнес-инкубатор для учащихся 9-11 классов, который помогает развивать необходимые в современном мире предпринимательские навыки. Так, на содействие малому бизнесу школьников было выделено более 200 грантов. Для поддержки талантливых и мотивированных детей Фонд неоднократно выделял гранты на обучение в Международной школе «Мирас» и в Astana IT University, а также помог казахстанским школьникам принять участие в престижном конкурсе «USTEM Robotics» в США. Авторские работы в рамках проекта «Тәлімгер», которому Фонд оказал поддержку, легли в основу учебной программы, учебников и учебно-методических книг по предмету «Основы предпринимательства и бизнеса», преподаваемого в 10-11 классах казахстанских школ и колледжей.

Помимо помощи школьникам, учащимся колледжей и студентам Фонд считает важным внести свой вклад в повышение квалификации педагогов, совершенствование их знаний и навыков, поскольку именно они являются проводниками знаний будущих поколений казахстанцев. При поддержке Фонда «Халык» в южной столице был организован ежегодный городской конкурс педагогов «Almaty Digital Ustaz.

Важной инициативой стал реализуемый проект по обучению основам финансовой грамотности преподавателей из восьми областей Казахстана, что должно оказать существенное влияние на воспитание финансовой грамотности и предпринимательского мышления у нового поколения граждан страны.

Необходимую помощь Фонд «Халык» оказывает и тем, кто особенно остро в ней нуждается. В рамках социальной защиты населения активно проводится работа по поддержке детей, оставшихся без родителей, детей и взрослых из социально уязвимых слоев населения, людей с ограниченными возможностями, а также обеспечению нуждающихся социальным жильем, строительству социально важных объектов, таких как детские сады, детские площадки и физкультурно-оздоровительные комплексы.

В копилку добрых дел Фонда «Халык» можно добавить оказание помощи детскому спорту, куда относится поддержка в развитии детского футбола и карате в нашей стране. Жизненно важную помощь Благотворительный фонд «Халык» оказал нашим соотечественникам во время недавней пандемии COVID-19. Тогда, в разгар тяжелой борьбы с коронавирусной инфекцией Фонд выделил свыше 11 миллиардов тенге на приобретение необходимого медицинского оборудования и дорогостоящих медицинских препаратов, автомобилей скорой медицинской помощи и средств защиты, адресную материальную помощь социально уязвимым слоям населения и денежные выплаты медицинским работникам.

В 2023 году наряду с другими проектами, нацеленными на повышение благосостояния казахстанских граждан Фонд решил уделить особое внимание науке, поскольку она является частью общественной культуры, а уровень ее развития определяет уровень развития государства.

Поддержка Фондом выпуска журналов Национальной Академии наук Республики Казахстан, которые входят в международные фонды Scopus и Wos и в которых публикуются статьи отечественных ученых, докторантов и магистрантов, а также научных сотрудников высших учебных заведений и научно-исследовательских институтов нашей страны является не менее значимым вкладом Фонда в развитие казахстанского общества.

С уважением,
Благотворительный Фонд «Халык»!

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UPLIFT BEHAVIOR OF PYRAMIDAL-PRISMATIC PILES IN CLAY SOIL

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Abstract. The field-testing results of large-scale models of reinforced concrete driven pyramidal-prismatic piles with different lengths of the pyramidal part are presented. The uplift bearing capacity of piles are estimated. It has been established that the uplift behavior of pyramidal-prismatic piles can be either greater (by 1.26–1.78 times) or less (by 13–51.0 %) compared with conventional prismatic and pyramidal piles. It was founded that the increasing the length of the pyramidal part of the testing piles increases their bearing capacity by 1.19–1.67 times. It is shown that the lifting out of piles from the soil base, regardless of their longitudinal shape, is characterized by a phase of "elastic resistance", a phase of "plastic resistance" and a phase of "avulsion", which sequentially follow each other. It is established that the loads values in the end of the "elastic resistance" phase and on the beginning of the "avulsion" phase depend on piles longitudinal shape, and for pyramidal-prismatic piles also on the length of their pyramidal part. It is revealed that the length of the pyramidal part of pyramidal-prismatic piles has a positive effect to the soil resistance forces along the lateral surface of the piles, including the elastic resistance forces of the soil. Correlation dependences for determining the uplift capacity of pyramidal-prismatic piles are proposed. The research results can be as the basis for the recommendations development for the calculation and design of pyramidal-prismatic piles.

Keywords: model, pyramidal-prismatic pile, soil, displacement, uplift, bearing capacity, ultimate resistance, lateral surface

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ПИРАМИДАЛЫҚ-ПРИЗМАЛЫҚ ҚАДАЛАРДЫҢ САЗДЫ ТОПЫРАҚТАҒЫ СУЫРЫП АЛУ ЖҮКТЕМЕСІНЕ ҚАРСЫЛЫҒЫ

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Аннотация. Пирамидалық бөліктің әр түрлі ұзындығына ие темірбетонды пирамидалық-призмалық қадалардың ауқымды модельдерін қолдана отырып, далалық жағдайда жүргізілген эксперименттердің нәтижелері көрсетілген. Қадалардың статикалық суырып алу жүктемесінің әсер ету қабілеті бағаланады. Пирамидалық-призмалық қадалардың тарту жүктемесінің жүк көтергіштігі әдеттегі призмалық және пирамидалық қадалармен салыстырғанда үлкен (1,26–1,78 есе) немесе аз (13–51,0 %) болуы мүмкін екендігі анықталды. Тәжірибелік қадалардың пирамидалық бөлігінің ұзындығының ұлғаюымен олардың жүк көтеру қабілетінің 1,19–1,67 есе артқаны анықталды. Бойлық пішініне қарамастан, қадаларды жерден суырып алу процесі бір-бірінен дәйекті түрде жүретін "серпімді қарсылық" фазасымен, "пластикалық қарсылық" фазасымен және "бөліну" фазасымен сипатталатыны көрсетілген. "Серпімді қарсылық" фазасының соңына және қадалардың "бөліну" фазасының басына сәйкес келетін жүктеме мәндері олардың бойлық пішініне, ал пирамидалық-призмалық қадалар үшін пирамидалық учаскенің ұзындығына байланысты екендігі анықталды. Пирамидалық-призмалық қадалардың пирамидалық учаскесінің ұзындығы қадалардың бүйір бетіндегі топырақтың қарсылық күштерін, соның ішінде топырақтың серпімді қарсылық күштерін іске асыруға оң әсер ететіні анықталды. Пирамидалық призмалық қадалардың жүк көтергіштігін анықтау үшін корреляциялық тәуелділіктер ұсынылған. Зерттеу нәтижелері пирамидалық призмалық қадаларды есептеу және жобалау бойынша ұсыныстарды әзірлеуге негіз болады.

Түйін сөздер: модель, пирамидалды-призмалық қада, топырақ, орын ауыстыру, суырып алу жүктемесі, жүк көтергіш қасиеті, шектік кедергісі, бүйір беті

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СОПРОТИВЛЯЕМОСТЬ ПИРАМИДАЛЬНО-ПРИЗМАТИЧЕСКИХ СВАЙ ВЫДЕРГИВАЮЩЕЙ НАГРУЗКЕ В ГЛИНИСТОМ ГРУНТЕ

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Аннотация. В статье изложены результаты экспериментов, выполненных в полевых условиях с применением крупномасштабных моделей железобетонных забивных пирамидально-призматических свай, обладающих разной длиной пирамидальной части, и оценена несущая способность свай действию статической выдергивающей нагрузки. Установлено, что несущая способность пирамидально-призматических свай выдергивающей нагрузке может быть как большей (в 1,26–1,78 раза), так и меньшей (на 13–51,0 %) по сравнению с обычными призматическими и пирамидальными сваями. Выявлено, что с увеличением длины пирамидальной части опытных свай имеет место увеличение их несущей способности в 1,19–1,67 раза. Показано, что для процесса выдергивания свай из грунта независимо от их продольной формы характерны фаза «упругого сопротивления», фаза «пластического сопротивления» и фаза «отрыва», которые последовательно следуют друг за другом. Установлено, что значения нагрузок, соответствующие концу фазы «упругого сопротивления» и началу фазы «отрыва» свай, зависят от их продольной формы, а для пирамидально-призматических свай еще и от длины пирамидального участка. Выявлено, что длина пирамидального участка пирамидально-призматических свай оказывает положительное влияние на реализацию сил сопротивления грунта по боковой поверхности свай, в том числе и сил упругого сопротивления грунта. Предложены корреляционные зависимости по определению несущей способности пирамидально-призматических свай. Результаты исследований служат основой для разработки рекомендаций по расчету и проектированию пирамидально-призматических свай.

Ключевые слова: модель, пирамидально-призматическая свая, грунт, перемещение, выдергивающая нагрузка, несущая способность, предельное сопротивление, боковая поверхность

Introduction

Hydraulic structures (trays, aqueducts, siphons, etc.), including marine hydraulic structures, as well as bridges, chimneys, towers, masts, lighthouses, high-rise buildings and a number of other structures are often subjected to horizontal and moment loads, causing their loss stability followed by overturning. Emergencies from such loads can occur during impacts of a moored sea vessel, tension of mooring cables, effects of waves, sea currents, mudflows, squally winds and floating ice, as well as during earthquakes, tsunamis, frosty heaving of soils, etc.

The resistance of structures against overturning is largely determined by the resistance of their foundation structures to lifting forces. Of the foundation structures that have a high bearing capacity to uplift load, piles and pile foundations can be especially distinguished. Currently, there are a number of studies devoted to the study of the piles resistance to an axial uplift load (Hanna et. a1., 1986: 387–392; Bose et. a1., 2009: 49–54; Nazir et. a1., 2013: 147–154; Gaaver et. a1., 2013: 365–372; Al-Neami et. a1., 2020: 1–12; Alex et. a1., 2018: 193–198; Mahmood et. a1., 2020: 13–20). The results of their brief analysis in order to identify factors that affect the uplift behavior of piles are given below.

The Hanna et. a1. (1986: 387–392) studied of driven piles models in sandy soil. They established the inclination of a pile (towards the vertical axis) in the soil affects its uplift capacity to lifting. This effect is due to a change in the passive pressure of sand along the perimeter of the pile during lifting from the soil base. The positive effect of the piles inclination angle to the uplift capacity is also noted by Bose et. a1. (2009: 49–54). By the numerical studies, they established that the piles maximum resistance in sandy soil occurs at an angle of inclination equal to 20º. It was also found that increasing the ratio of the pile depth L to its diameter d also increases the pile bearing capacity. It has been determined that a pile with a circle cross section resists to lifting load better than a pile with a square section. The high bearing capacity of a pile with a circular section compared to a pile with a square and rectangular section is also indicated in (Nazir et. a1., 2013: 147–154). The researchers also found that the bearing capacity of piles with a rough (not smooth) side surface is 18–75 % greater than piles with a smooth surface.

Partly different data are presented in (Gaaver et. a1., 2013: 365–372). Studies using models of pile bushes, consisting of 2, 4 and 6 piles, revealed that their uplift capacity decreases with an increase in the L/d ratio. The authors notes that the pile bushes bearing capacity in sands slightly depends on their density. More detailed data on the effect of sand density on the resistance of vertical and inclined piles are presented in (Al-Neami et. a1., 2020: 1–12). As a result of numerical studies, the authors found that the increasing sand's density by 40–80 %, the maximum lifting force increases by 1.67–2.12 times for a vertical pile, and by 1.68–2.22 times for an inclined pile with tilt angle 20º. The influence of the soil type on the piles resistance to lifting-out loads is indicated in (Alex et. a1., 2018: 193–198). So the researchers estimated that the bearing capacity of piles in dense sand is 4.4 % more than in silty soil and 17.5 % more than in clay soil.

Mahmood et. a1. (2020: 13–20) studies the uplift behavior of steel piles in water-saturated soils. According to their tests, a tubular pile with a hollow circular cross section, compared with an I-beam and a hollow square pile, has better resistance. Authors explain this effect when a round pile is lifted out, due to the shape of pile cross section; the contact stresses in the soil stratum along the perimeter of the pile section are distributed more evenly than in piles with other cross-sectional shapes. It follows such important factors as the type of soil, its density, the amount of penetration of the pile into the soil, the angle of its inclination to the vertical, the condition of the side surface of the pile and the shape of its cross section. However, despite this, the influence of the shape of the piles longitudinal section on their resistance to lifting loads remains unexplored to date. The relevance of this issue is causes using in construction industry a number of piles with different longitudinal shaft shapes. These include pyramidal piles, flat-profile piles, piles with flat triangular shaft extensions, pyramidal-prismatic piles, etc. (Bekbasarovet.a1., 2020: 909–917, 2021:53–63, Abbasov, 2006: 230).

Considering the above mentioned, the authors carried out experimental studies to assess the uplift resistance of pyramidal-prismatic piles in comparison with prismatic and pyramidal piles.

This paper discusses the results of studies of pyramidal-prismatic piles (hereinafter – PPP), developed in the geotechnical laboratory of the M.Kh. Dulaty Taraz Regional University (Bekbasarov et.a1., 2019:134–141). Due to the combined design (pyramidal upper and prismatic lower parts), these piles, compared to prismatic piles, have a higher bearing capacity to an axial and lateral loads (Bekbasarov et.a1., 2021: 909–917).

The purpose of this research is a comparative assessment of uplift behavior of the PPPin clay soil to static lifting-out loads.

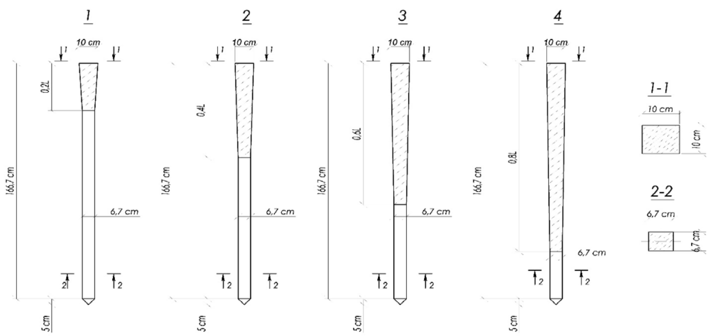
To achieve this goal, the following tasks were solved:

- the features of the influence of the PPP pyramidal part'slength on their resistance to lifting-out loads were revealed;
- the PPP and prismatic and pyramidal shapespilesresistance were comparativelyrated.

Piles parameters, equipment features and research methods. The tests were carried out in the field site using large-scale pile models. The geometric scale of pile models (hereinafter referred to as piles) is taken as equal to 1:3. The piles are made of reinforced concrete with non-stressed longitudinal reinforcement and transverse reinforcement of the shaft. The piles length *L* was 166.7 cm. The experimental piles were made with a pyramidal section of 0.2L (33.3 cm), 0.4L (66.7 cm), (Fig. 1, a). As control (comparable) piles are accepted:

- prismatic pile with cross-sectional dimensions of 6.7×6.7 cm;
- prismatic pile with cross-sectional dimensions of 10.0×10.0 cm;
- pyramidal pile with cross-sectional dimensions in the upper part 10.0 × 10.0 cm and in the lower part - 6.7 × 6.7 cm.

The slope of the side faces of the pyramidal pile to the vertical was $i_p = 0.01$.



a)

b)

Figure 1. Schemes (a) and fragments (b) of the testing piles large-scale models

Piles were tested at the test site of the industrial base of the South-Kazakhstan branch of KazNIISA JSC. The experimental site's soil base was composed of hard-plastic sandy loam. The physical and mechanical characteristics of the soil were determined by the penetration method using the PSG MG-4 (Table 1).

Table 1. Physical and mechanical characteristics of the experimental site soil

Characteristics	The values
Humidity, W, %	3,16-5,58
Density, ρ, kg/m^3	1400-1670
Moisture at the pour point, W_m, %	24,18-24,37
Moisture at the rolling edge, W_p, %	17,30-17,47
Plasticity number, I_p	6,88-6,90
Maximum penetration resistance, P_{max}, MPa	1,47-1,62
Compaction factor, K	0,89-0,94
Index (degree) of humidity, I	0,75-0,84
Deformation modulus, E, MPa	31,6-33,6
Internal friction angle, φ, grade	17,1-17,6
Specific adhesion, c, MPa	0,018-0,019

For piles driving and testing, special experimental equipment was developed and manufactured (Fig. 1b). Features, principles and procedures of working this equipment are presented in (Bekbasarov et.a1., 2019).

Piles were tested to assess their bearing capacity in accordance with the requirements of GOST 5686–2012. "Soils. Methods of field testing with piles" (GOST 5686–2012, 2014). A step-increasing uplift load was applied to the piles until the "avulsion" phase is come. This phase means the rapid exit-out of a significant part of the pile to the soil surface without applying any additional load. The bearing capacity of piles based on test results was determined in accordance with the requirements of SP RK 5.01-103-2013 "Pile Foundations" (SP RK 5.7.01-103-2013, 2015).

Research results

The pile tests results are presented in Figure 2, as well as in Tables 2 and 3.

The uplift bearing capacity of piles according to the test results was determined in accordance with the requirements of SP RK 5.01-103-2013 "Pile foundations" (SP RK 5701-103-2013, 2015) by the formula:

$$F_d = \frac{\gamma_c \times F_{u,n}}{\gamma_g}, \qquad (1)$$

where: $F_{u,}$ – the coefficient of pile working conditions, taken equal to 1,0; $F_{u,n}$ – the standard value of the ultimate resistance of the pile, taken equal to its smallest ultimate resistance according to the test results; γ_g – the soil safety factor, taken equal to 1,0.

The characteristic value of pile lifting-out resistance was determined in accordance with the requirements of SP RK EN 1997-1:2004/2011 Geotechnical design [SP RK EN 1997-1:2004/2011, 2016] using the formula:

$$R_{t;k} = \frac{(R_{t;m})_{\min}}{\xi_2}, \qquad (2)$$

where: $(R_{c;m})_{min}$ – the smallest value of the measured value of the soil compressive resistance depending on the number of tests; ξ_2 – a correction factor for evaluating the results of testing pile models, taken equal to 1.40 (for n = 1); n is the number of tests of pile models.

Table 2 Values of the bearing capacity $F_{d,v}$ and the characteristic value of the resistance $R_{t;k}$ of piles to lifting-out load

Pile type	Bearing capacity of the pile $F_{d,v}$, N	Characteristic value of pile resistance $R_{t;k}$, N
Experimental piles: PPP 1 (with cross-sectional dimensions on top 10.0×10.0 cm and a pyramidal part 0.2L length)	1200	814,28
PPP 2 (as mentioned, with a pyramidal part of 0.4L length)	1428	1020
PPP 3 (as mentioned, with a pyramidal part of 0.6L length)	1715	1225
PPP 4 (as mentioned, pyramidal part 0.8L length)	2012	1437,14
Control piles: prismatic pile with cross section dimensions 6.7×6.7 cm	1130	807,14
prismatic pile with cross section dimensions 10.0×10.0 cm	1435	1025

pyramidal pile with the dimensions of the upper section 10.0×10.0 cm and the lower section - 6.7×6.7 cm	2308	1648,57
Note: L is the length of the PPP's pyramidal part without the tip		

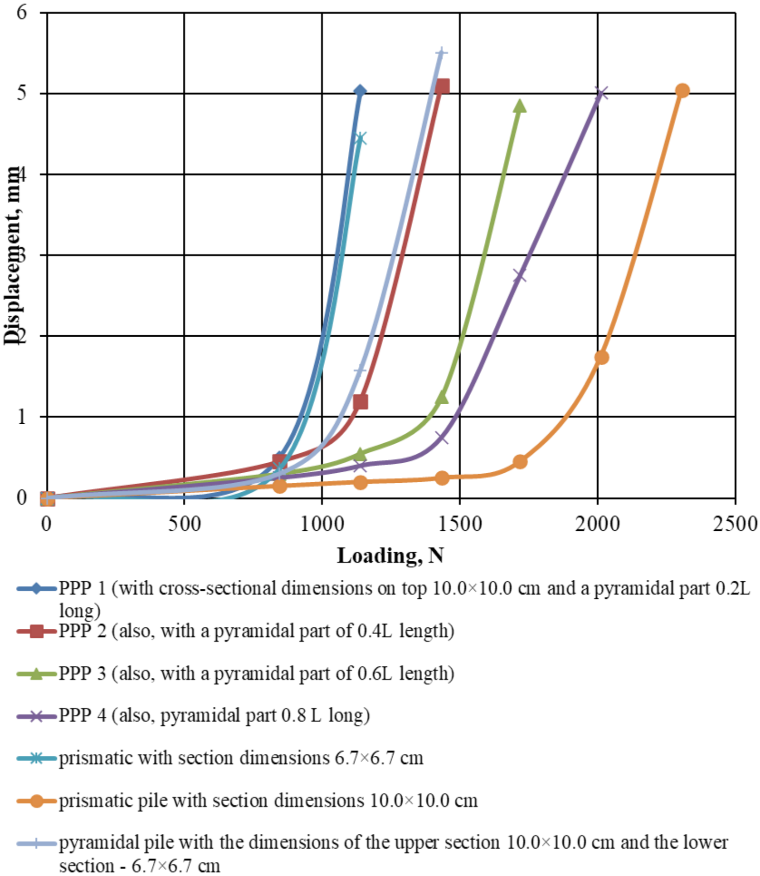


Figure 2. Dependence of the vertical displacement of piles on the static lifting-out load

Comparative evaluation of the uplift resistance of piles was carried out on the basis of their relative lifting-out efficiency coefficients J_v and J_{vx}, which were determined by the formulas:

$$J_v = \frac{F^{o}_{d,v}}{F^{\hat{e}}_{d,v}}, \qquad (3)$$

$$J_{vx} = \frac{R^{o}_{t;k;v}}{R^{\hat{e}}_{t;k;v}} \qquad (4)$$

where: $F^{o}_{d,v}$ - bearing capacity of the experimental pile; $R^{o}_{t;k\,v}$

- bearing capacity of the control pile; $R^{o}_{t;k\ v}$
- characteristic value of the experimental pile; $R^{\hat{e}}_{t;k\ v}$
- characteristic value of the control pile.

Table 3. Values of relative efficiency coefficients of pile pulling J_v (J_{vx})

Relative efficiency ratios	Coefficient values for experimental piles with the length of the pyramidal part			
	0,2L	0,4L	0,6L	0,8L
J_{v1} (J_{vx1})	1,0	1,26	1,52	1,78
J_{v2} (J_{vx2})	0,79	0,99	1,19	1,40
J_{v3} (J_{vx3})	0,49	0,62	0,74	0,87
Note: $J_{v1}(J_{vx1})$, $J_{v2}(J_{vx2})$ and $J_{v3}(J_{vx3})$ – coefficients related respectively to a prismatic pile with section dimensions of 6.7 × 6.7 cm, a prismatic pile with section dimensions of 10.0 × 10.0 cm and a pyramidal pile with section dimensions on top of 10.0 × 10.0 cm and bottom - 6.7 × 6.7 cm.				

The research results allow us to highlight the following features of the experimentalpile driving process:

- the bearing capacity of the PPP with the length of the pyramidal section (0.4÷0.8) L is 1.26–1.78 times greater than the bearing capacity of a prismatic pile with a section size of 6.7×6.7 cm;
- the bearing capacity of the PPP with the length of the pyramidal section (0.6 ÷ 0.8) L is 1.19–1.40 times greater, and the PPP with the length of the pyramidal section (0.2 ÷ 0.4) L - by 1.0–21.0 % less than the bearing capacity of a prismatic pile with a section size of 10.0×10.0 cm;
- PPP resistance is 13.0–51.0 % lower than a pyramidal pile;
- the PPP pyramidal section length increasing by 2.3 and 4 times leads to resistance increasing by 1.19, 1.43, 1.67 times, respectively.

Analysis of the graphs presented in Fig. 2 shows that uplift loading of pile, before the "avulsion" phase, the pile passes:

- the phase of "elastic resistance", which is characterized by a linear dependence of the pile displacement on the load;
- the phase of "plastic resistance", which is characterized by a curvilinear dependence of the pile displacement on the load.

These phases of the uplift process of the pile follow each other in sequence and finish with the "avulsion" phase. Displacements of piles within their "elastic resistance" phase reach 0.1– 0.22 mm, and the load in this case reaches up to 780–1620 N (Table 4). Moreover, the maximum load N_y, causing elastic displacement of the pile, related of the pyramidal pile. The values of the considered load for the PPP are 1.22–2.38 times less than for the pyramidal pile, and depend on the length of their pyramidal part. Increasing the length of the pyramidal part of the PPP by 2, 3 and 4 times is causes an increasing the load N_y by 1.46, 1.90 and 1.94 times, respectively. For PPP, the load values N_y turned out to be 1.27–1.83 times higher than for prismatic piles. The exception is the load value N_y coming to the PPP with a pyramidal section length of 0.2L. Which, on the contrary, turned out to be 1.06-1.15 times less than for prismatic piles.

Table 4 – Uplift load values N_y corresponding to the end of the phase"elastic resistance" of piles

Type of pile	Load, N_y, N
Experienced piles: PPP 1 (with cross-sectional dimensions on top 10.0×10.0 cm and a pyramidal part 0.2L length)	680
PPP 2 (as mentioned, with a pyramidal part of 0.4L length)	990
PPP 3 (as mentioned, with a pyramidal part of 0.6L length)	1290
PPP 4 (as mentioned, pyramidal part 0.8L length)	1320
Control piles: prismatic with section dimensions 6.7×6.7 cm	720
prismatic pile with section dimensions 10.0×10.0 cm	780
pyramidal pile with the dimensions of the upper part 10.0×10.0 cm and the lower part - 6.7×6.7 cm	1620

Considering the uplift load, the piles resistance is determined only by the resistance of the soil stratum along their lateral surface. Therefore, the calculation of the ultimate soil resistance f_{pr} (Table 5) was performed. This parameter is sets as the ratio of the load N_o corresponding to the beginning of the "avulsion" phase of the pile to the area of contact of its side surface with the soil A_f. It should be noted that the resistance f_{pr} represents the forces of friction and the forces of compression of the pile in the soil layer.

Table 5 - Values of ultimate soil resistance along the lateral surface of piles f_{pr}.

Type of pile	The area of the lateral surface of the submerged part of the pile A_f, cm^2	Load N_o , N	Ultimate soil resistance f_{pr}, N/cm^2
Experienced piles: PPP 1 (with cross-sectional dimensions on top 10.0×10.0 cm and a pyramidal part 0.2L length)	3928	1137,96	0,29
PPP 2 (as mentioned, with a pyramidal part of 0.4L length)	4104	1432,26	0,35
PPP 3 (as mentioned, with a pyramidal part of 0.6L length)	4308	1716,75	0,40
PPP 4 (as mentioned, pyramidal part 0.8L length)	4520	2011,05	0,45
Control piles: prismatic with section dimensions 6.7×6.7 cm	3900	1137,96	0,29
prismatic pile with section dimensions 10.0×10.0 cm	5820	1432,26	0,25
pyramidal pile with the dimensions of the upper section 10.0×10.0 cm and the lower section - 6.7×6.7 cm	4736	2305,35	0,48

Table 5 shows that the maximum resistance value f_{pr} is typical for a pyramidal pile, and the minimum value is for a prismatic pile with a section size of 10×10 cm and 6.7×6.7 cm turned out to be the same. The values of soil resistance f_{pr} for PPP are

1.07-1.66 times less than for a pyramidal pile, and 1.16–1.80 times greater than for a prismatic pile with a section size of 10×10 cm. Increasing the length of the pyramidal part of PPP by 2.3 and 4 times leads to an increase in the ultimate soil resistance f_{pr}, respectively, by 1.2, 1.38 and 1.55 times.

Correlation dependencies. The test results presented in Table 2 are described by the following linear functions:

$$F^{o}_{d,v} = F^{k}_{d,v1} + \Delta_F \ , \quad (5)$$

$$F^{o}_{d,v} = F^{k}_{d,v2} - \Delta_F \ , \quad (6)$$

$$F^{o}_{d,v} = F^{k}_{d,v3} - \Delta_F \ , \quad (7)$$

$$\Delta_F = gl + d \ , \quad (8)$$

where: $F^{k}_{d,v2}$, $F^{k}_{d,v2}$, $F^{k}_{d,v3}$ - bearing capacity, respectively, of a prismatic pile with section dimensions of 6.7 × 6.7 cm, a prismatic pile with section dimensions of 10 × 10 cm and a pyramidal pile with section dimensions in the upper part of 10 × 10 cm and in the lower part - 6.7 × 6, 7 cm, N;Δ_F – the difference between the values of the bearing capacity of experimental and control piles, N; g and d - coefficients taken according to Table 6; l - length of the pyramidal part of the PPP, cm.

Table6 -The values of the coefficients *g* and *d* in the formula (8)

The value of Δ_F in the formula	Coefficient values		Approximation confidence level (R^2)
	g, N/cm	*d,* N	
(5)	272,3	222	0,99
(6)	129,9	50	0,91
(7)	-272,3	1400	0,99

The data presented in Table 3 is mathematically described by the following linear function:

$$J_{vp} = al + b \ , \quad (9)$$

where:*l* – same as in formula (8),*a*and *b*-coefficients taken according to Table 7.

Table 7 - The values of the coefficients *a* and *b* in the formula (9)

Relative efficiency coefficients for uplift	Coefficient values		Approximation confidence level (R^2)
	a, 1/cm	*b*	
J_{vp1}	0,26	0,74	1
J_{vp2}	0,203	0,585	0,999
J_{vp3}	0,126	0,365	0,997

Conclusion

The presented results of experimental studies of the PPP allow us to make the following conclusions:

- depending on the length of the pyramidal section, PPP, in comparison with prismatic piles, have both higher and lower bearing capacity to uplift load;
- the resistance of the PPP is lower than the resistance of the pyramidal pile;
- uplift behavior of piles, regardless of their longitudinal shape, has specific phases such as "elastic resistance", "plastic resistance" and "avulsion" phases, which sequentially follow each other;
- load values corresponding to the end of the “elastic resistance” phase and the beginning of the “avulsion” phase of the piles depend on their longitudinal shape, and for the PPP, on the length of the pyramidal part;
- the length of the PPP pyramidal section has a positive effect on the implementation of soil resistance forces along their lateral surface, including the forces of elastic soil resistance;
- between the bearing capacity of the PPP and the bearing capacity of prismatic and pyramidal piles, there are certain patterns that are described by correlation dependencies with a fairly high accuracy.

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