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ХАБАРЛАРЫ

ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК
РЕСПУБЛИКИ КАЗАХСТАН
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TAPERED-PRISMATIC PILE: DRIVING ENERGY CONSUMPTION AND BEARING CAPACITY

Abstract. The laboratory tests of models of driven pyramidal-prismatic and prismatic piles for pressing vertical loads are presented. Laboratory tests were carried out on reduced piles models (M 1:10) with different lengths and cross-sections of the pyramidal segment. It was found that with an increase in the length of the pyramidal segment of pile models, the energy costs for driving them increase by 7.12-27.26%, the bearing capacity of the pile models increases by 28.36-55.38%. It was revealed at the same driving depth and the same settlements, the bearing capacity of the models of pyramidal-prismatic piles is 1.5-4.01 times higher than the model of a prismatic pile with a cross-section of 20 × 20 mm, and compared to the model of a prismatic pile with a cross-section 30 × 30 mm can be either 1.23-1.92 times more or 8-35% less, depending on the length and size of the cross-section of the pyramidal segment of the experimental pile models. A correlation dependence has been obtained, making it possible to predict the bearing capacity of pyramidal-prismatic piles with known values of traditional prismatic piles' bearing capacity. The revealed features of the behavior of pyramids-long-distance-prismatic piles allow to reasonably assign the length and dimensions of the cross-section of their pyramidal segment.

Key words: Small-scale modeling, Sand, Pile foundation, Tapered pile, Pile driving, Bearing capacity, Settlement.

Introduction. Piles of various longitudinal shapes are widely used, including tapered piles, conical piles, and piles with broadening (widening) of the shaft.

When driving traditional prismatic piles in the soil layer's upper zone at a depth of 1.0-1.5 m, there is asignificant loosening of the soil around the lateral surface of the pile. Decompaction of the soil occurs due to the impact on the soil by horizontal vibrations on the top of the pile from hammer blows. Within the specified depth between the surface of the pile and the soil layer (in the contact zone), cracks are formed up to 2-3 cm wide and up to 40-50 cm deep (Medvedeva et al. 2000). Violation of the soil structure, adecrease in its natural density, and the formation of cracks in the soil's upper zone cause a decrease in the pile's bearing capacity along its lateral surface.

The experiments on driving piles into sandy soils carried out by Anusich et al. (2019) showed an increase in piles' bearing capacity with an increase in the number of impacts. The authors attribute this to the fact that a high frequency of impacts contributes to achieving the maximum «long-term» bearing capacity of the pile.

Kupchikova et al. (2017) note that the upper spreading of the pile promotes the expansion of the contact zone of the pile's lateral surface with the surrounding soil and ensures their close contact a positive effect on increasing the bearing capacity of the pile. Such soil entrainment occurs in cohesive soils since spreading piles can compact the surrounding soil (Hosseiniet al. 2017) and, as a result, increase the overall bearing capacity. Pusztai (2014) show the increase in bearing capacity of the small spreading piles driving into an incompressible layer of sandy soil.

According to Isaev et al. (2016), tapered piles make it possible to increase its vertical load-bearing capacity. Movahedi (2018) comes to the same conclusions, speaking about the increase in piles' load resistance with inclined edges. The author connects this with the depth of the pile's immersion and the pile's compression by soil in the spreading segment of the pile (Movahedi Rad, M. 2017).

Bekbasarovet al. (2020) study indicates a greater bearing capacity of piles with flat tapered spreading. Comparative studies of spreading piles and prismatic piles have shown that spreading piles' bearing capacity increases 1.09-1.56 times in clay soils.

Sorochanyet al. (1993) studied the regularities of the operation of tapered piles in swelling soils: the dependence of their rise on the taper angle, pile length, and transmitted load. The authors investigated the layer-by-layer soil deformations around the pile and the soil deformation's dependence on the pile immersion depth.

Several studies (Kamran et al. 2008, Hassan et al. 2019, Zotcenko et al. 2018, Esmaili et al. 2013) indicate the economic feasibility of using piles, in which the upper cross-section is larger than the lower cross-section. The test results showed that piles with inclined edges (with an angle of inclination from 0.95 to 1.91) have a higher (up to 50%) bearing capacity than conventional straight piles. Investigation of the behavior of tapered pile foundations in loose sandy soils with different inclination angles (20°, 30° and 45°) revealed a decrease in sedimentary deformation of the foundations. So, the coefficient of bearing capacity of such a foundation reached 88.5%, and the coefficient of subsidence reduction - 37.3%. Besides, it was revealed that piles' settlement with inclined edges in clayey soils is close to the value of the settlement of a group of straight piles.

In comparison with prismatic piles (with the same material consumption), conical piles' use increased the proportion of the load taken by the side surface of the pile up to 75%. At the same time, the bending stiffness of conical piles was 2-2.5 times higher. The cost of foundations made of such piles was evaluated as less than prismatic piles foundations up to 60% (Bartolomei et al. 2001).

Khabbaz and Shafaghat (2015, 2020) shown that for the soil with a high angle of internal friction, conical piles' bearing capacity is larger than other piles of the same volume.

The driven reinforced concrete piles with spreading in the upper part were developed in the Taraz Regional University (Taraz, Kazakhstan) for the foundation of hydraulic engineering structures (Bekbasarov et al. 2019). The developed pile structures had a combined (tapered-prismatic) shape, containing both a tapered (upper) and a prismatic (lower) part. Considering the effectiveness of these piles, the authors carry out experimental and theoretical analysis. It was confirmed (Shanshabayev 2020) that tapered-prismatic piles are more effective than prismatic piles under static vertical loads.

The publications discussed above have shown that the presence of inclined side faces increases the pile's bearing capacity. However, the influence of pile segment' parameters with inclined lateral faces (length, width, angle of inclination, etc.) remains not fully investigated. This motivates laboratory studies of models of pyramidal-prismatic piles with variable parameters of a segment with inclined edges.

This study aims to evaluate the influence of the length and cross-section size of the tapered segment of tapered-prismatic piles on their driving energy intensity (submersion) and bearing capacity in laboratory conditions using piles' models.

The research object was driven piles of variable cross-section, consisting of a prismatic bottom and tapered upper segments.

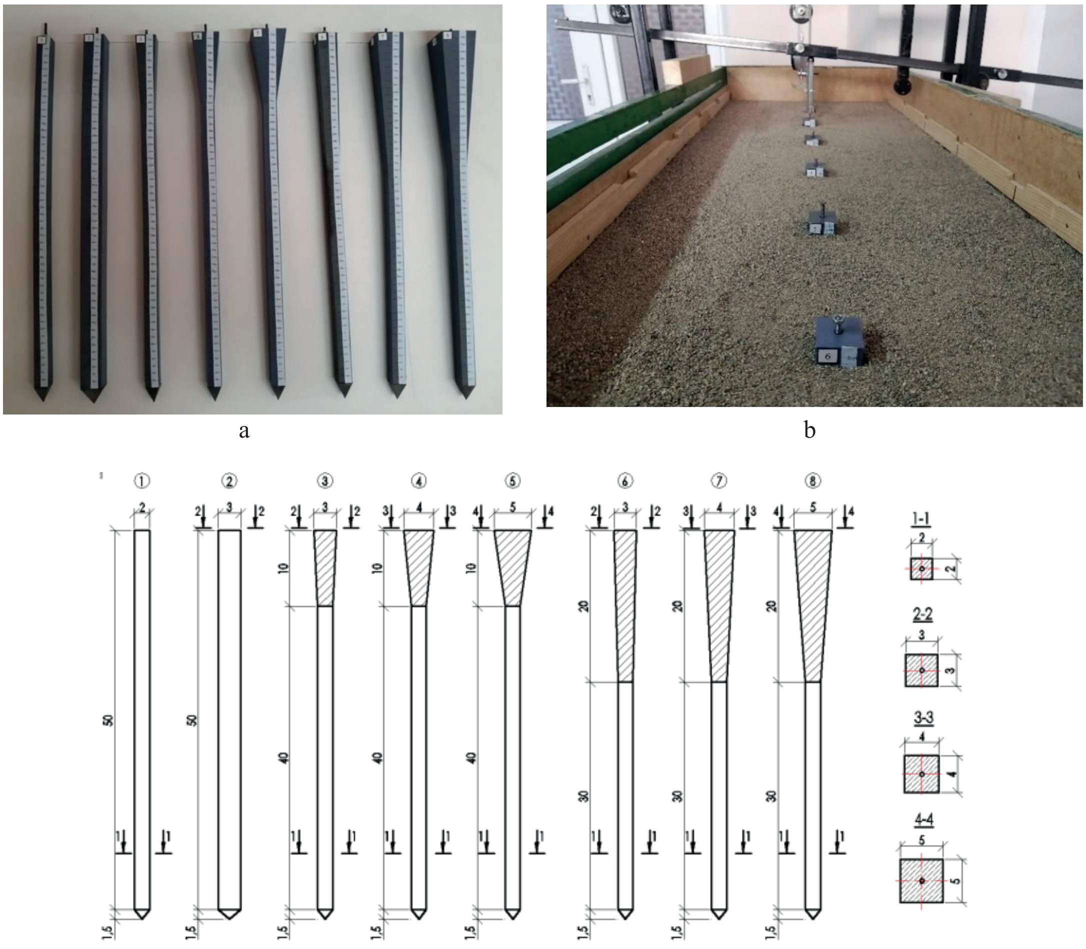
The study's subject was the piles' bearing capacity and the energy consumption of pile driving at different geometrical dimensions of the taped segment of the pile.

Methods and materials. Models of piles were made by fused deposition (FDM) and printed on a CreatBot DX PLUS 3D printer (Henan Suwei Electronic Technology Co., LTD. Zhengzhou City, Henan Province, China). The consumable material of the models is ABS Plus plastic (China). The modeling scale is taken equal to 1:10, the deviations of the sizes of modelsarising in the technological process of 3D printing do notexceed 0.02 mm.

Models of experimental piles were made with tapered segments 10 and 20 cm long. The cross-sections of the top of the tapered segment were 30 × 30 mm, 40 × 40 mm, and 50 × 50 mm, and the cross-sections of the bottom of the tapered segment was 20 × 20 mm.

The length of the prismatic segment of the pile models was 40 and 30 cm, and the cross-section was 20 × 20 mm. The length of the pile models was 50 cm.

The following control (compared) models were made: a prismatic pile with a cross-sectional at 20 × 20 mm and 30 × 30 mm. Table 1 presents the pile models' sizes and their mass.



a b

c

Figure 1.General view (a), a fragment of pile pressure test (b) and diagram (c) of pile models

1-model of a prismatic pile with a cross-section of 20 × 20 mm; 2- model of a prismatic pile with a cross-section of 30 × 30 mm; 3- model tapered-prismatic pile with cross-sectional dimensions on top of 30 × 30 mm and tapered segment 10 cm long; 4- model tapered-prismatic pile with a cross-section on top of 40 × 40 mm and a tapered segment with a length of 10 cm; 5- model tapered-prismatic pile with cross-section dimensions on the top 50 × 50 mm and tapered with a 10 cm long segment; 6- model tapered-prismatic pile with cross-sectional dimensions on top of 30 × 30 mm and tapered segment 20 cm long; 7- model tapered-prismatic pile with a cross-section on top of 40 × 40 mm and a tapered segment with a length of 20 cm; 8- model tapered-prismatic pile with cross-section dimensions on the top 50 × 50 mm and tapered with a 20 cm long segment.

Table1 - Sizes of pile models and their mass

Pile model number and type	Sizes, mm			Mass, g
	Shaft length, mm	Tip length, mm	Shaft cross-sectional dimensions, mm	
Control models: 1. Prismatic 2. Prismatic	500	15	20×20 30×30	270 560
Test models: 3. Tapered-prismatic pile with cross-sectional dimensions. 30 × 30/20 × 20mm and tapered by a 10cm long segment; 4. Tapered-prismatic pile with a cross-sectional area of 40 × 40/20 × 20 mm and a tapered segment with a length of 10 cm; 5. Tapered-prismatic pile with cross-sectional dimensions 50 × 50/20 × 20 mm and tapered segment 10 cm long;	500	15	-	300 330 360

6. Tapered-prismatic pile with a cross-sectional area of 30 × 30/20 × 20 mm and a tapered segment with a length of 20 cm;				330
7. Tapered-prismatic pile with a cross-sectional area of 40 × 40/20 × 20 mm and a tapered segment with a length of 20 cm;				360
8. Tapered-prismatic pile with cross-sectional dimensions 50 × 50/20 × 20 mm and a tapered segment with a length of 20 cm;				460
Note: there are the cross-sectional dimensions of the tapered pile segment in the upper part before the slash, and there are the cross-sectional dimensions in the lower part after the slash.				

The experiments were carried out in tray equipped with multipurpose-hinged laboratory equipment based on the laboratory «Nanoengineering Research Methods» Taraz Regional University named after M.Kh. Dulati (Taraz, Kazakhstan). Features, principles, and order of operation of the used equipment outlined in Bekbasarov et al. (2020).

Sandy soil preparation was carried out as follows. The pre-dried soil was sieved through a sieve with a hole diameter of 2 mm. Before lying, the sandy soil was moistened to a uniform moisture content. The prepared soil was laid in a tray in layers, with a thickness of each layer equal to 10 cm. Each layer of soil was thoroughly leveled and rolled. A total of 7 layers of soil were laid. The soil's physical and mechanical characteristics were determined in each series of experiments using the PSG MG-4 device (OOO Special Design Bureau Storeypribor, Chelyabinsk, Russia). Table 2 presents the physical and mechanical characteristics of sandy soil.

Table2 - Physical and mechanical characteristics of sandy soil

No	Characteristics	The values
1	Humidity W,%	9.98-10.32
2	Density ρ, g/cm^3	1.33-1.41
3	Maximum resistance to penetration Pmax, MPa	0.270-0.275
4	Compaction factor K	0.81-0.84
5	Moisture index (degree) I	0.91-0.93
6	Deformation modulus E, MPa	15.1-15.9
7	Internal friction angle f, degrees	13.0-13.1
8	Specific adhesion c, MPa	0.0109-0.0110

The pile models were driven into the ground with a striker to approximately the same depth at a constant energy of each impact. The mass of the striker was 600 g, and the height of its dropping - equal to 500 mm. The immersion depth of the pile models was 441-447 mm (maximum difference - 1.34%).

Results. Tables 3 and 4 show the results of the driving of the test models and control models of piles. At the same time, the comparison of the energy consumption of driving pile models was assessed according to the following indicators:

- the specific energy consumption of driving E_v, taken as the ratio of the total potential energy of strikes of the striker spent on driving the model to the volume of its submerged part in the ground;
- coefficient of the relative power consumption of driving K_E, taken as the ratio of the total potential energy of striker impacts spent on driving the experimental model of the pile to a similar energy parameter of the control model of the pile.

Table3 - Pile **model** driving results

Pile cross-section, cm	Tapered segment length, cm	Total energy of blows spent on driving E, J, (number of blows)	Immersion depth L, mm	The volume of the immersed part V, cm^3	Specific energy consumption of plugging E_v, J/cm^3
30×30/20×20	10	123.6 (42)	471	200.9	0.615
40×40/20×20	10	129.5 (44)	471	214.1	0.605
50×50/20×20	10	167.7 (57)	471	229.6	0.703
30×30/20×20	20	132.4 (45)	470	220.8	0.560
40×40/20×20	20	164.8 (56)	470	264.1	0.624

50×50/20×20	20	188.3 (64)	470	316.7	0.595
20×20	0	117.7 (40)	470	190.0	0.619
30×30	0	294.3 (100)	470	427.5	0.688

Notes. The cross-section of the pyramidal segment of the pile in the upper part is indicated before the slash. The dimensions of the lower part are indicated after the slash. Two bottom lines of the table correspond to prismatic piles.

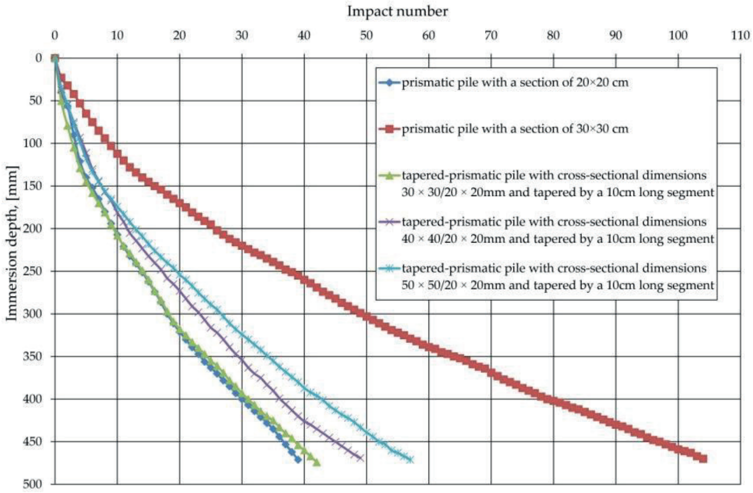


Figure 2. Dependence of the immersion depth of pile models on the number of blows

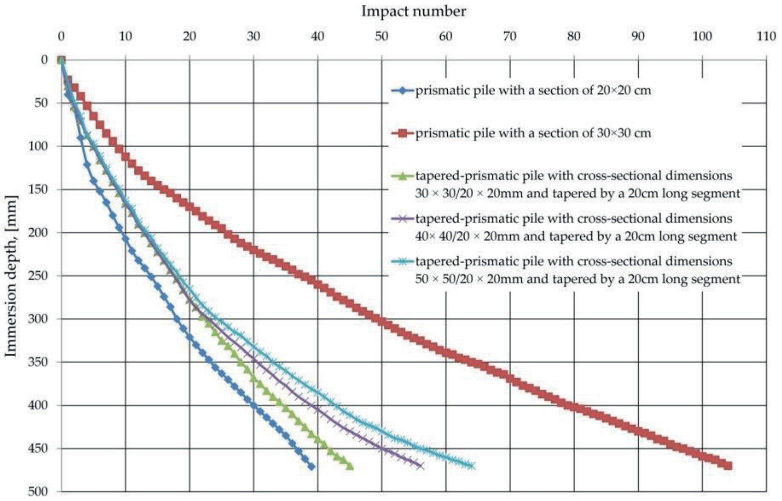


Figure 3. Dependence of the immersion depth of pile models on the number of blows

Table4 - Relative energy intensity of driving K_E of pile models

Coefficients of the relative energy intensity of driving pile models	Tapered segment sizes					
	30×30/ 20×20 (10cm)	40×40/ 20×20 (10 cm)	50×50/ 20×20 (10 cm)	30×30/ 20×20 (20 cm)	40×40/ 20×20 (20 cm)	50×50/ 20×20 (20 cm)
K_{E1}	1.05	1.10	1.42	1.12	1.40	1.60
K_{E2}	0.42	0.44	0.57	0.45	0.56	0.64

Notes.

1. Coefficients K_{E1} and K_{E2}, respectively, refer to the prismatic pile models with a cross-section size of 20 × 20 mm and a prismatic pile with a cross-section size of 30 × 30 mm;
2. The cross-section sizes of the tapered segment of the pile in the upper part are indicated before the slash. The dimensions in the lower part are indicated after the slash;
3. The length of the tapered segment of the pile is shown in brackets.

Static tests were carried out for the action of vertical indentation loads to assess the pile models' bearing capacity. The pressing load was transferred to the pile models in a step-by-step mode to provide conditional stabilization of their settlement following Russian State Standard GOST 5686-2020 «Soils. Field test methodsbypiles» 2014. This standard applies to methods of field-testing of soils with full-scale piles, reference piles, probe piles, carried out during engineering surveys for construction, for control tests of soils with piles during construction, and reconstruction. Static loading of the models was carried out up to a draft of at least 40 mm.

The test results are shown in Fig. 4 and 5 and in Tables 5-6. A comparative assessment of the resistance of pile models to the action of an indentation load was carried out according to the following indicators:

- bearing capacity F_d, determined in accordance to Interstate Standard «Soils. Field test methodsbypiles» 2014;
- specific bearing capacity F_d^V, taken as the ratio of the bearing capacity of the pile model to the volume of its submerged part in the soil;

The coefficient of the relative efficiency of the models by the bearing capacity K_N was used for piles efficiency evaluation. This coefficient was taken as the ratio of the pile's experimental model's bearing capacity to the similar pile's control model's bearing capacity.

Table5 - Bearing capacity F_d and specific bearing capacity F_d^V of pile models.

Pile cross-section, cm	Tapered segment length, cm	Bearing capacity of the pile model, F_d, N, at settlement		Specific bearing capacity of the pile model, F_d^V, N/cm^3, at settlement	
		20 mm	40 mm	20 mm	40 mm
30×30/20×20	10	151.2	176.3	0.752	0.877
40×40/20×20	10	193.2	226.1	0.902	1.05
50×50/20×20	10	284.0	332.1	1.24	1.44
30×30/20×20	20	200.1	226.3	0.906	1.02
40×40/20×20	20	300.2	332.5	1.14	1.26
50×50/20×20	20	430.0	470.1	1.36	1.48
20×20	0	105.1	117.2	0.553	0.617
30×30	0	231.3	245.1	0.541	0.573

Table6 - Coefficients of the relative efficiency of pile models by the bearing capacity K_N at a settlement at 20 and 40 mm

Coefficients of the relative efficiency of pile models by the bearing capacity	Tapered segment sizes, cm					
	30×30/ 20×20 (10 cm)	40×40/ 20×20 (10 cm)	50×50/ 20×20 (10 cm)	30×30/ 20×20 (20 cm)	40×40/ 20×20 (20 cm)	50×50/ 20×20 (20 cm)
at settlement20 mm						
K_{N1}	1.44	1.84	2.70	1.90	2.85	4.10
K_{N2}	0.65	0.83	1.23	0.86	1.30	1.86
at settlement40 mm						
K_{N1}	1.50	1.93	2.83	1.93	2.84	4.01
K_{N2}	0.72	0.92	1.35	0.92	1.36	1.92

Notes:
1. Coefficients K_{N1} and K_{N2}, respectively, refer to the model of a prismatic pile with a cross-section size of 20 × 20 mm and a model of a prismatic pile with a cross-section size of 30 × 30 mm;
2. The upper part dimensions of the tapered segment are given before the slash. The lower part dimensions of the tapered segment are given after the slash;
3. The length of the tapered segment of the pile is shown in brackets.

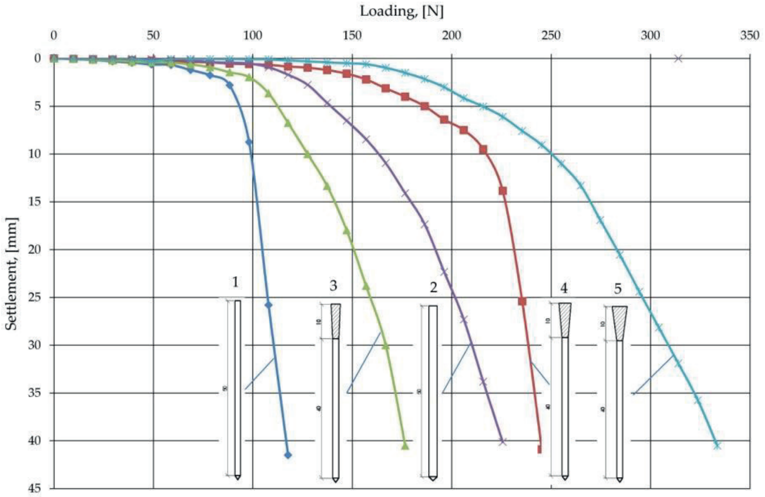


Figure 4. Dependence of settlement of pile models on static indentation load

1-model of a prismatic pile with a cross-section of 20 × 20mm;

2- model of a prismatic pile with a cross-section of 30 × 30mm;

3- model tapered-prismatic pile with cross-sectional dimensions on top of 30 × 30 mm and tapered segment 10 cm long;

4- model tapered-prismatic pile with a cross-section on top of 40 × 40 mm and a tapered segment with a length of 10 cm;

5- model tapered-prismatic pile with cross-section dimensions on the top 50 × 50 mm and tapered with a 10 cm long segment.

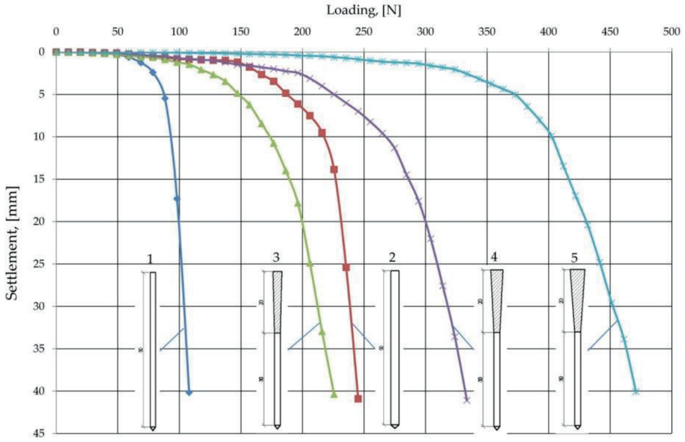


Figure 5. Dependence of settlement of pile models on static indentation load

1- model of a prismatic pile with a cross-section of 20 × 20 mm;

2- model of a prismatic pile with a cross-section of 30 × 30mm;

3- model tapered-prismatic pile with cross-sectional dimensions on top of 30 × 30 mm and tapered segment with a length of 20 cm;

4- model tapered-prismatic pile with a cross-section on top of 40 × 40 mm and a tapered segment with a length of 20 cm;

5- model tapered-prismatic pile with cross-sectional dimensions on top of 50 × 50 mm and tapered segment with a length of 20 cm.

The data presented in tables 5 and 6 are mathematically described by the following second-order polynomial function

$$K_H = an^2 + bn + c \tag{1}$$

where: K_N is the coefficients of the relative efficiency of pile models by the bearing capacity of the tapered-prismatic pile; n is the cross-sectional dimension of the top of the tapered portion of the tapered-prismatic pile: *a*, *b* and *c* are the coefficients taken according to table 7.

Table 7**-** Coefficients *a*, *b*, and *c* in approximation (1) at the settlement at 20 and 40 mm

Coefficients of the relative efficiency of piles by the bearing capacity	Coefficients *a*, *b*, and *c* in approximation (1)					
	a, 1/m^2, (10cm)	*b*, 1/m, (10cm)	*c* (10cm)	*a*, 1/m^2, (20cm)	*b*, 1/m, (20cm)	*c* (20cm)
at 20 mm						
K_{N1}	0.23	0.29	1.5	0.15	0.5	1.25
K_{N2}	0.11	0.15	0.69	0.06	0.26	0.54
at 40 mm						
K_{N1}	0.235	0.275	1.54	0.13	0.52	1.28
K_{N2}	0.115	0.145	0.75	0.06	0.26	0.6
Note: the length of the prismatic segment of the pile is indicated in brackets.						

The indices of the value of the reliability of approximation R_2 of the experimental data according to the formula (1) are equal to 1.0, which indicates its high reliability. The formula can be used to predict the bearing capacity of test piles with known values of the bearing capacity of the control piles.

Discussion. 1. Comparative analysis of the values of the total energy consumption *E* and the specific energy consumption E_v of the models of the experimental and control piles allows us to distinguish the following regularities (tables 3, 4):

- an increase in the length of the tapered segment of the test piles by 10 cm is accompanied by an increase in the total energy costs for their driving by 7.12-27.26%;
- an increase in the size of the upper cross-section of the tapered segment of the test piles by 1.33 and 1.66 times leads to an increase in the total energy costs for their driving by 4.77-24.47% and 35.68-42.22%, respectively;
- among the experimental piles, the highest total energy costs are typical for piles with a tapered segment length of 20 cm and an upper cross-section size of 50 × 50 mm.
- the total energy costs for driving experimental piles are 1.05-1.6 times higher than for driving a prismatic pile with a cross-section of 20 × 20 mm and 36-58% less than for driving a prismatic pile with a cross-section of 30 × 30 mm;
- the specific energy consumption of piles with a tapered segment length of 10 cm (0.605 to 0.703 J/cm^3) is slightly higher than that of piles with a tapered segment 20 cm long (0.560-0.624 J/cm^3).

2. Comparison of the values of the bearing capacity of the models of the experimental and control piles allows us to establish the following features (tables 4-6):

- an increase in the length of the tapered segment of the test piles by 1 m causes an increase in their bearing capacity by 32.34-55.38% at a settlement of 20 mm and by 28.36-47.06% at a settlement of 40 mm;
- an increase in the size of the cross-section of the tapered segment of the test piles by 1.33 and 1.66 times is accompanied by an increase in their bearing capacity, respectively, by 27.77-50.02 and 87.83-114.95% at settlements of 20 mm, and by 28.25-46.92 and 88, 37-107.73% at 40 mm precipitation;
- an increase in the length of the tapered segment of the test piles by 10 cm leads to an increase in their specific bearing capacity by 9.68-26.38% at a settlement of 20 mm and by 2.77-20.0% at a settlement of 40 mm;
- an increase in the size of the cross-section of the tapered segment of the test piles by 1.33 and 1.66 times provides an increase in their specific bearing capacity, respectively, by 19.95-25.83% and 50.11-64.89% at settlements of 20 mm, and by 19.73-23.53 and 45.1-64.20% at precipitation of 40 mm;
- the specific bearing capacity of the test piles is1.36-2.46 times higher than the specific bearing capacity of a prismatic pile with a cross-section size of 20 × 20 mm, and 1.30-2.58 times higher than that of a prismatic pile with a cross-section size 30 × 30 mm;

- the bearing capacity of the test piles exceeds the bearing capacity of a prismatic pile with a cross-section size of 20 × 20 mm by 1.44-4.1 times at a settlement of 20 mm and by 1.5-4.01 times at a settlement of 40 mm;
- depending on the length and dimensions of the cross-section of the tapered segment, the bearing capacity of the test piles can be 1.23-1.92 times higher or 8-35% less than the bearing capacity of a prismatic pile with a cross-section size of 30 × 30 mm.

Conclusions. Based on the presented research results, the following main conclusions can be formulated:

- energy costs for driving tapered-prismatic piles, as well as their resistance to the action of a vertical indentation load, depending on the length and dimensions of the cross-section of the top of the tapered segment, with an increase in which the energy intensity of immersion and the bearing capacity of the test piles increase;
- it was revealed that the energy consumption of driving tapered-prismatic piles (depending on the length and size of the upper cross-section of the tapered segment) is 1.05-1.6 times higher than that of prismatic piles with a cross-section of 20 × 20 mm and 36-58% lower compared with a pile with a cross-section of 30 × 30 mm;
- with the same driving depth and with the same pile settlements, the bearing capacity of tapered-prismatic piles is 1.5-4.01 times higher than that of a prismatic pile with a cross-section of 20 × 20 mm, and in comparison with a prismatic pile with a cross-section of 30 × 30 mm it can be, both 1.23-1.92 times more and 8-35% less, depending on the length and size of the tapered segment of the test pile;
- the obtained correlation dependence makes it possible to predict the bearing capacity of tapered-prismatic piles with known values of the bearing capacity of traditional prismatic piles.

The revealed characteristic features of tapered-prismatic piles' behavior will make it possible to reasonably assign the length and dimensions of the cross-section of their tapered segment.

The results of the field tests of the tapered piles are presented in Bekbasarov et al. (2021).

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ПИРАМИДАЛЫ-ПРИЗМАТИКАЛЫҚ ҚАДАЛАР МОДЕЛЬДЕРІНІҢ ЭНЕРГИЯ СЫЙЫМДЫЛЫҒЫ ЖӘНЕ ЖҮК КӨТЕРУ ҚАБІЛЕТІ

Аннотация. Пирамидалық-призмалық және призмалық қадалардың модельдерін қағу бойынша және тік батыру жүктемелеріне зертханалық сынақтар жүргізілді. Зертханалық сынақтар пирамидалық бөлігінің ұзындығы мен қимасы әртүрлі қадалар модельдерімен (М 1:10) жүргізілді. Қадалық модельдердің пирамидалық бөлігінің ұзындығы ұлғайған сайын оларды қағуға жұмсалатын энергия шығындары 7,12-27,26%-ға артады, қадалар модельдерінің жүк көтергіштігі 28,36-55,38%-ға өседі. Пирамидалы-призмалық қадалар модельдерінің жүк көтергіштігі көлденең қимасының өлшемі 20 × 20 мм призмалық қадалар моделіне қарағанда 1,5-4,01 есе жоғары, ал көлденең қимасының өлшемі 30 × 30 мм призмалық қадалар моделімен салыстырғанда, эксперименттік қадалар модельдерінің пирамида бөлігінің көлденең қимасының ұзындығымен мөлшеріне байланысты 1,23-1,92 есе артық немесе 8-35% кем болуы мүмкін екендігі анықталды. Дәстүрлі призмалық қадалардың белгілі жүктеме мәндерімен пирамидалық призмалық қадалардың жүк көтеру қабілетін болжауға мүмкіндік беретін корреляциялық тәуелділіктер ұсынылды. Пирамидалық- призмалық қадалардың анықталған ерекшеліктері олардың пирамидалық бөлігінің көлденең қимасының ұзындығымен өлшемдерін дұрыс таңдауға мүмкіндік береді.

Түйінді сөздер: шағын көлемді модельдеу, құм, қадалық іргетас, пирамидалы-призмалық қадалар, қадақағу, жүк көтеру қасиеті, шөгу.

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ЭНЕРГОЕМКОСТЬ ЗАБИВКИ И НЕСУЩАЯ СПОСОБНОСТЬ МОДЕЛЕЙ ПИРАМИДАЛЬНО-ПРИЗМАТИЧЕСКИХ СВАЙ

Аннотация. Проведены лабораторные испытания моделей забивных пирамидально-призматических и призматических свай забивкой и навдавливающие вертикальные нагрузки. Лабораторные испытания проводились на моделях свай (М 1:10) с различной длиной и сечением пирамидального участка. Установлено, что с увеличением длины пирамидального участка свайных моделей затраты энергии на их забивку увеличиваются на 7,12-27,26%, несущая способность моделей свай возрастает на 28,36-55,38%. Выявлено, что при одинаковой глубине забивки и одинаковых осадках несущая способность моделей пирамидально-призматических свай в 1,5-4,01 раза выше, чем у модели призматической сваи сечением 20 × 20 мм, а по сравнению с моделью призматической сваи сечением 30 × 30 мм может быть в 1,23-1,92 раза больше или на 8-35% меньше, в зависимости от длины и размера поперечного сечения пирамидального участка экспериментальных моделей свай. Получена корреляционная зависимость, позволяющая прогнозировать несущую способность пирамидально-призматических свай с известными значениями несущей способности традиционных призматических свай. Выявленные особенности поведения пирамидально-призматических свай позволяют обоснованно задавать длину и размеры поперечного сечения их пирамидального участка.

Ключевые слова: мелкомасштабное моделирование, песок, свайный фундамент, пирамидально-призматическая свая, забивка свай, несущая способность, осадка.

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