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Driving Features of Tapered-Prismatic Piles and Their Resistance to Static Loads

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Abstract
The field tests of large-scale models of driven tapered prismatic and prismatic piles for driving static vertical and horizontal loads are presented. Field tests were carried out on sandy loam on piles models (M 1:3) with different lengths and cross-sections of the pyramidal segment. It has been established that the driving of tapered-prismatic piles is accompanied by both large (by 1.10-1.60 times) and lower (by 8.0-37.0%) energy consumption for their driving in comparison with conventional prismatic and pyramidal piles. It was also revealed that under the vertical pressing load, the bearing capacity of the tapered-prismatic piles is 1.09-1.48 times, and under the horizontal static load, it is 1.17-1.80 times higher than the prismatic pile. It has been established that with an increase in the length of the pyramidal part of the experimental piles, there is an increase in their bearing capacity by 1.12-1.34 times. Equations are proposed for determining the bearing capacity of tapered-prismatic piles. The research results serve as the basis for the development of recommendations for the calculation and design of tapered-prismatic piles. The revealed features of the behaviour of tapered-prismatic piles allow to reasonably assign the length and dimensions of the cross-section of their pyramidal segment.

Keywords
model, tapered-prismatic pile, soil, driving, testing, load, settlement, bearing capacity

Introduction

Piles of various longitudinal shapes are widely used, including tapered piles, conical piles, and piles with a 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 a significant 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 (Bekbasarov, Isakov & Amanbai, 2014; Bekbasarov, 2021; Medvedeva & Bulankin, 2000). Violation of the soil structure, a decrease 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. These negative phenomena were avoided by the use of driven piles widening to the top (Kupchikova & Kurbatskiy, 2017; Isaev, Maltsev & Karpov, 2016).

The experiments on driving piles into sandy soils carried out by (Anusich et al., 2018) 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 & Kurbatskiy (2017) note that the upper widening 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 has 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 (Hosseini & Rayhani, 2017) and, as a result, increase the overall bearing capacity. (Pusztai, 2014) show the increase in bearing capacity of the small widening 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, 2017).

Bekbasarov & Atenov (2020) study indicates a greater bearing capacity of piles with flat tapered widening. Comparative studies of widening piles and prismatic piles have shown that first piles' bearing capacity increases 1.09-1.56 times in clay soils.

Bakholdin & Igonkin (1978) show that the maximum effect from tapered piles can be obtained only in soils with relatively high modulus of deformation and angles of internal friction; in sands, loamy sands, loams with a low plasticity index, loess-like loams, and loess. Tapered piles in high ductility clays show less resistance to stress.

Sorochan & Lee (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; Blanchet et al., 1980; Zotcenko et al., 2018; Esmaili & Hataf, 2013) indicate the economic feasibility of using piles, 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 behaviour 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 - was 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.

Dmohovsky (1927) carried out the first work on the study of the behaviour of conical piles in the soil in Russia. He pointed out that giving the lateral surface of the pile even an insignificant taper increases the pile's total resistance by a factor of 5-9. 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 by up to 60% (Bartolomei & Ponomorev, 2001).

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

The driven reinforced concrete piles with widening in the upper part were developed at the Taraz Regional University (Taraz, Kazakhstan) for the foundation of hydraulic engineering structures (Bekbasarov & Shanshabaev, 2019). The developed pile structures had a combined (tapered-prismatic) shape, containing both a tapered (upper) and a prismatic (lower) part. Considering these piles' effectiveness, the authors conduct an experimental and theoretical analysis. It was confirmed (Bekbasarov & Shanshabaev, 2019; 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 tapered-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 by piles of variable cross-sections consisting of 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.

The results of the preliminary calculation performed earlier, presented by (Bekbasarov & Shanshabaev, 2019; 2020), show that the shape of the tapered-prismatic piles (hereinafter referred to as TPP) affects their bearing capacity, which is significantly different from the bearing capacity of pyramidal and prismatic piles.

In the framework of experimental studies at the initial stage, the authors carried out experiments using small-scale models of TPP in a soil flume (in laboratory conditions), the results of which are presented by (Bekbasarov & Shanshabaev, 2020; 2020).

The purpose of the work is to assess the energy intensity of driving (submersion) of tapered-prismatic piles, as well as their resistance to indentation and horizontal loads using large-scale models in the field side.

Characteristics of pile models, equipment and research methods

Models of piles are made of solid one-piece reinforced concrete with tension-free longitudinal reinforcement and transverse reinforcement of the shaft. The scale of models (hereinafter referred to as piles) is taken as 1:3. Experimental piles were made with a tapered (pyramidal) section from 33 cm to 133.2 cm long (Fig. 1). To compare the research results, three models were adopted as control piles: a prismatic pile with a cross-sectional size of 6.7×6.7 cm, a prismatic pile with a cross-sectional size of 10.0×10.0 cm, and a pyramidal pile with a cross-sectional size in the upper parts 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. The weight of the pile was determined by weighing it on a scale and amounted to N: TPP-1 – 198.1; TPP-2 –212.7; TPP-3 –226.3; TPP-4 – 241.1; prismatic (6.7×6.7 cm) – 180.5; prismatic (10.0×10.0 cm) – 386.5; pyramidal – 258.0.

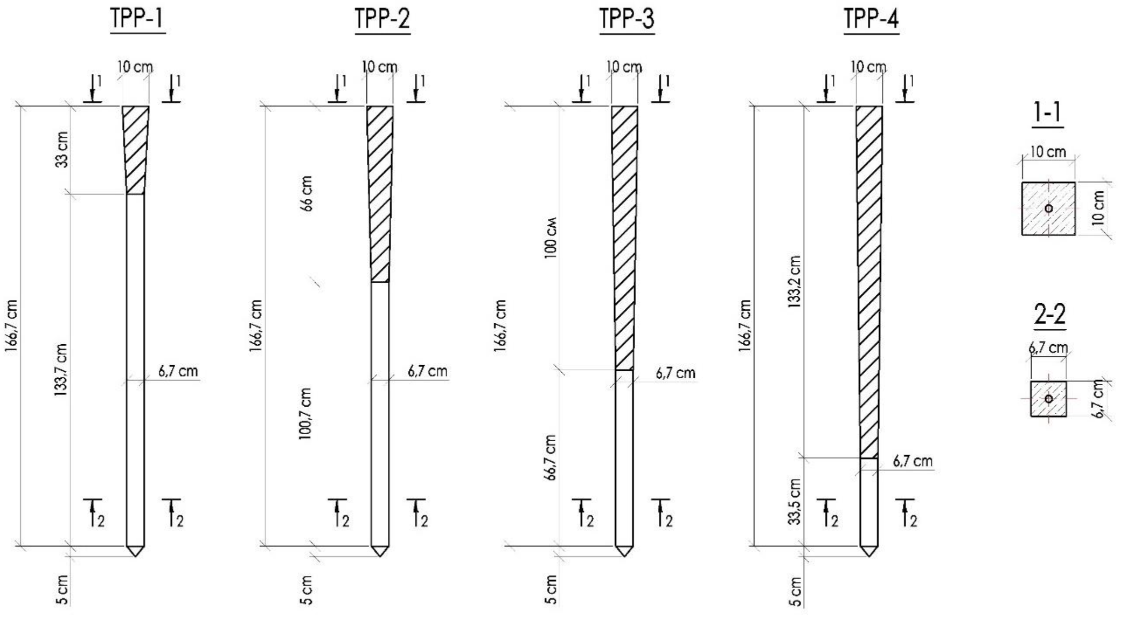


Fig. 1. Diagram of pile models

Field tests were carried out at the test site of the production base of the South Kazakhstan branch of the "Kazakh Research and Design Institute of Construction and Architecture" JSC. The experimental site, with dimensions in plan 6.0×3.0 m and a depth of 3.0 m, was composed of sandy loam. Site preparation included layer-by-layer laying and uniform compaction of soil from the bottom of a previously dug excavation. The physical and mechanical characteristics of the soil were established by the penetration method using the PSG MG-4 device (Tab. 1).

Tab. 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

Special experimental equipment was developed and manufactured for driving and testing pile models (Fig. 2). Parameters, principles and sequence of using this equipment are presented in (Bekbasarov & Shanshabaev, 2019).

The piles were driven into the ground by hammering them at the constant energy of each impact. A striker weighing 40 kg was dropped from a constant height of 0.5 m. The pile depth was 145.0-145.5 cm (the maximum difference between depths was 0.34%).

a)

b)

c)

Fig. 2. Fragments of pile driving (a) and their tests for pressing (b) and horizontal (c) loads.

Tests of pile models to assess their bearing capacity were carried out in accordance with the requirements of GOST 5686-2012. "Soils. Methods of field testing with piles" (2014) by stepwise increasing loading of piles with a static indentation load with the provision of the required conditional stabilization of their settlement. Power loading of each pile was carried out to a settlement of at least 40 mm. The bearing capacity of the piles was determined in accordance with the requirements of SP RK 5.01-103-2013 "Pile foundations" (2015).

Tests of piles for horizontal loading (Fig. 2, c) were carried out until their head part reached at least 10 mm. The next steps of the horizontal load were applied to the pile after the movement of its head reached the required level of conditional stabilization.

Research results

Information about the number of blows to piles, the energy consumption of the striker for driving them, as well as the depth and volume of the submerged part of the piles are presented in Tab. 2. The pile driving records are shown in Fig. 3.

The assessment of the submersion and energy intensity of the pilot and control models of piles based on field tests was carried out on the basis of the following indicators:

- the number of blows of the striker spent on driving the pile model (Tab. 2);
- specific energy consumption of driving the pile model E_v, taken as the ratio of the total potential energy of the striker's impacts spent on driving the model to the volume of its submerged part in the ground (Tab. 2);
- the coefficient of the relative energy intensity of driving the pile model K_e, taken as the ratio of the total potential energy of blows of the striker spent on driving the experimental model of the pile to the same energy parameter of the control pile model (Tab. 3).

Tab.2. Results of pile models driving

Pile type	The total energy of impacts spent on the hammering E, J (number of blows)	Immersion depth L, cm	Submerged volume V, cm^3	Specific energy consumption of driving E_v, J/cm^3
Experienced piles: TPP-1	9914.4 (54)	145.5	8367.2	1.18
TPP-2	11016.0 (60)	145.4	9263.8	1.20
TPP-3	12301.2 (67)	145.0	9494.69	1.29
TPP-4	14320.8 (78)	145.0	10267.3	1.40
Control piles: Prismatic (6.7×6.7 cm)	8996.4 (49)	145.2	6592.83	1.36
Prismatic (10×10.0 cm)	15606.0 (85)	145.0	14666.6	1.06
Pyramidal (10.0×10.0/6.7×6.7 cm)	16891.2 (92)	145.0	9947.0	1.70

Tab. 3. Coefficient values of the relative energy consumption of driving K_e of pile models

Coefficients of relative power consumption of hammering	Coefficient values for experimental piles models with the length of the pyramidal section			
	TPP-1	TPP-2	TPP-3	TPP-4
K_{e1}	1.10	1.24	1.37	1.60
K_{e2}	0.63	0.70	0.79	0.92
K_{e3}	0.58	0.65	0.73	0.85

Note - Coefficients K_{e1}, K_{e2} and K_{e3}, respectively, refer to models of the prismatic pile with a cross-sectional area of 6.7×6.7 cm, a prismatic pile with a cross-sectional area of 10.0×10.0 cm and a pyramidal pile with a cross-sectional area of 10.0×10.0 cm above and 6.7 × 6.7 cm – below.

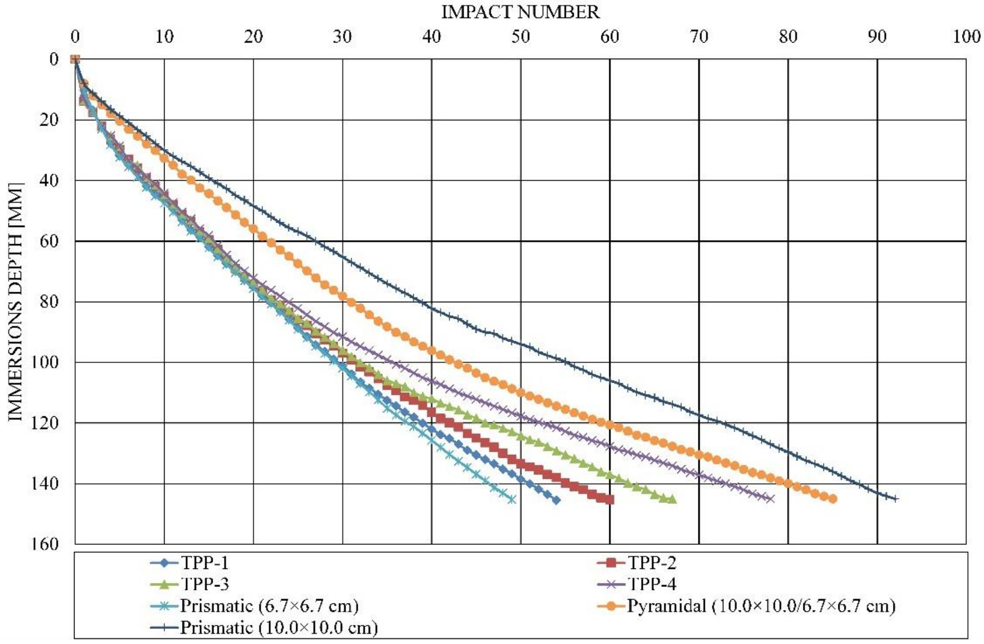


Fig. 3. Pile driving records

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

- depending on the length of the pyramidal part of the TPP, with the same immersion depth, the experimental piles, compared to prismatic and pyramidal piles, can have both large (1.10-1.60 times) and smaller (8.0-37.0%) energy consumption for driving;
- energy consumption for immersion of 1 m^3 of TPP is 1.03-1.32 times more and 5.43-44.07% less than for prismatic and pyramidal piles;
- with an increase in the length of the pyramidal part of the TPP, the energy costs for driving them to the same depth increase by 1.16-1.44 times.

The results of field tests of piles under the action of a vertical static load are presented in Tables 4-5. Graphs of the dependence of the settlement of pile models on the vertical load are shown in Fig. 4.

A comparative assessment of the resistance of pile models to the action of an indentation load was carried out on the basis of the following indicators:

- bearing capacity F_d, determined by the formula, taking into account the requirements of SP RK 5.01-103-2013 "Pile foundations" (Tab. 4):

$$F_d = \gamma_c \frac{F_{u,n}}{\gamma_g}, \tag{1}$$

where: γ_c – 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 the soil resistance to compression in the ultimate state in terms of bearing capacity $R_{c;k}$, determined by the equation in accordance with the requirements of SP RK EN 1997-1: 2004/2011 Geotechnical design. Part 1. General rules (2016):

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

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

- specific bearing capacity F_d^v, taken as the ratio of the bearing capacity of the pile to the volume of its submerged part in the ground (Tab. 4);
- the coefficient of the relative efficiency of the pile model in terms of bearing capacity K_n (by the characteristic value of soil compression resistance K_x), taken in the form of the ratio of the bearing capacity (characteristic value of the soil compressive resistance) of the experimental pile model to the similar force parameter of the control pile model.

Tab. 4. Bearing values F_d and specific bearing capacity F_d^v of piles, as well as the characteristic value of the soil compression resistance $R_{c;k}$

Pile type	Pile bearing capacity F_d, N, at settlement		Specific bearing capacity of the pile F_d^v, N/cm^3, at settlement		Characteristic value of soil compression resistance $R_{c;k}$, N, at settlement	
	20 mm	40 mm	20 mm	40 mm	20 mm	40 mm
<u>*Experienced piles:*</u> TPP-1	6100	7470	0.73	0.89	4357.14	5335.71
TPP-2	6820	7860	0.74	0.85	4871.43	5614.28
TPP-3	7310	8300	0.77	0.87	5221.43	5928.57
TPP-4	8175	9340	0.80	0.91	5839.28	6671.48
<u>*Control piles:*</u> prismatic (6.7×6.7 cm)	5500	6825	0.83	1.03	3928.57	4875.0
prismatic (10.0×10.0 cm)	8125	8975	0.55	0.61	5803.57	6410.71
pyramidal (10.0×10.0/6.7×6.7 cm)	9250	11625	0.99	1.17	6607.14	8303.57

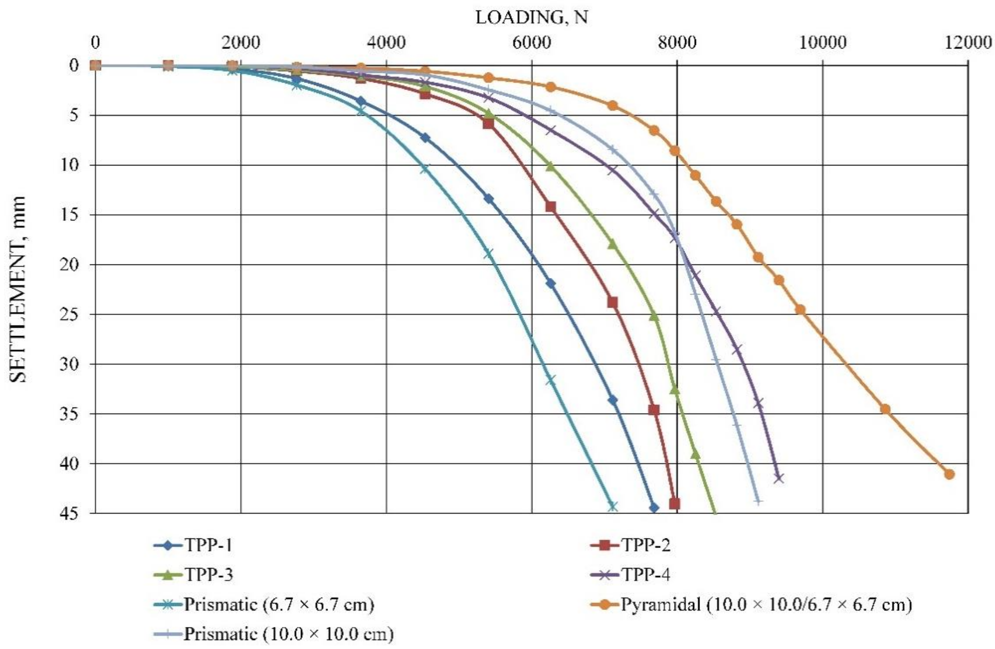


Fig. 4. Pile settlement versus the static pressing load

Tab. 5. Coefficient values of the relative efficiency of pile models for bearing capacity K_n at pile settlement at 20 mm and 40 mm

Relative efficiency coefficients for bearing capacity of models	Coefficient values for experimental models of piles with the length of the pyramidal part			
	TPP-1	TPP-2	TPP-3	TPP-4
at 20 mm				
K_{n1}	1.11	1.24	1.32	1.48
K_{n2}	0.75	0.84	0.90	1.0
K_{n3}	0.66	0.74	0.79	0.88
at 40 mm				
K_{n1}	1.09	1.15	1.21	1.37
K_{n2}	0.83	0.87	0.92	1.04
K_{n3}	0.64	0.67	0.71	0.80
Note - Coefficients K_{n1}, K_{n2}, K_{n3}, respectively, refer to models of a prismatic pile with a cross-sectional area of 6.7×6.7 cm, a prismatic pile with a cross-sectional area of 10.0×10.0 cm and a pyramidal pile with a cross-sectional area of 10.0×10.0 cm above and 6.7×6.7 cm - below				

The results of static tests of piles make it possible to establish the following features of the operation of experimental piles (at the same settlements):

- in comparison with a prismatic pile with a cross-sectional area of 6.7 × 6.7 cm, TPP have a higher bearing capacity (1.09-1.48 times);
- in comparison with a prismatic pile with a cross-sectional size of 10.0 × 10.0 cm, TPP with a pyramidal section length of 33-133.2 cm has less (by 8.0-25.0%), and TPP with a pyramidal section length of 133.2 cm – have greater (1.04 times) bearing capacity;
- compared to a pyramidal pile (with dimensions at the top 10.0×10.0 cm and at the bottom - 6.7 × 6.7 cm), TPP have a lower (by 20.0-36.0%) bearing capacity;
- the specific bearing capacity of the test piles is higher than the specific bearing capacity of a prismatic pile with a section size of 10.0 × 10.0 cm: with a pile settlement at 20 mm - 1.33-1.45 times; with the settlement at 40 mm - 1.46-1.49 times;
- with an increase in the length of the tapered (pyramidal) part, the bearing capacity of the test piles (at the same settlement values) increases by 1.12-1.34 times.

The results of testing piles for horizontal loading performed in the field tests are presented in Tables 6 and 7, as well as in Fig. 5.

Comparative assessment of the resistance of piles to the action of the horizontal (transverse) load was carried out on the basis of the coefficient of the relative efficiency of pile models in horizontal displacement K_{gp} (transverse load resistance K_{tr}).

Coefficient K_{gp} (K_{tr}) is set as the ratio of bearing capacity $F_{d,gp}$ (lateral load resistance R_{tr}), an experimental model of a pile (with a horizontal movement of 10 mm of its head) to a similar force parameter of the control pile model.

Tab. 6. Bearing values $F_{d,gp}$ and lateral load resistance R_{tr} of piles with horizontal displacement of their head by 10 mm

Pile type	Pile bearing capacity $F_{d,gp}$ (pile lateral load resistance R_{tr}), N	Bearing capacity for horizontal loads related to the pile volume N/cm^3
Experienced piles: TPP-1	2255	0.27
TPP-2	2580	0.28
TPP-3	2835	0.30
TPP-4	3450	0.34
Control piles: prismatic (6.7×6.7 cm)	1918	0.29
prismatic (10.0×10.0 cm)	4310	0.29
pyramidal (10.0 × 10.0/6.7×6.7 cm)	4030	0.41

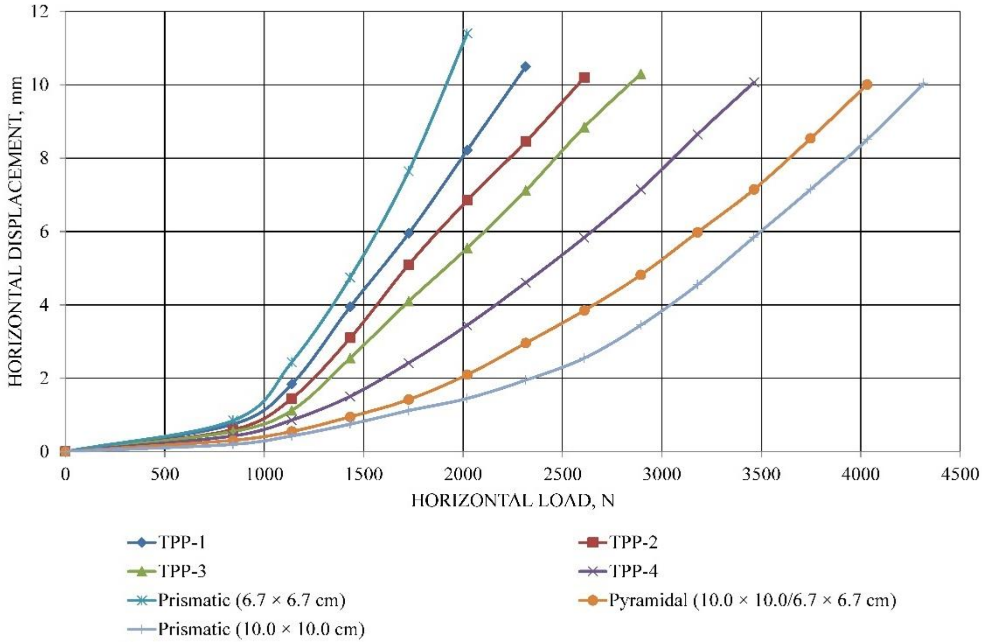


Fig. 5. Displacement of the piles head versus the static horizontal load

Tab. 7. The values of the coefficients of the relative efficiency of experimental piles for horizontal displacement K_{gp} (transverse load resistance K_{tr})

Relative efficiency ratios	Coefficient values for experimental models of piles with the length of the pyramidal part			
	TPP-1	TPP-2	TPP-3	TPP-4
K_{gp1} (K_{tr1})	1.17	1.35	1.48	1.80
K_{gp2} (K_{tr2})	0.52	0.60	0.65	0.80
K_{gp3} (K_{tr3})	0.56	0.64	0.70	0.85
Note - K_{gp1} (K_{tr1}), K_{gp2} (K_{tr2}), K_{gp3} (K_{tr3})– coefficients related to the models of a prismatic pile with a cross-sectional area of 6.7×6.7 cm, a prismatic pile with a cross-sectional area of 10.0×10.0 cm and a pyramidal pile with a cross-sectional area of 10.0×10.0 cm, and to the bottom - 6.7×6.7 cm.				

From Tables 6 and 7, the following patterns of behaviour of experimental piles under the action of a horizontal load are following:

- the bearing capacity of the TPP is 1.17-1.80 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 TPP is 20.0-48.0% less than the bearing capacity of a prismatic pile with a section size of 10.0 × 10.0 cm;
- the bearing capacity of the TPP is 15.0-44.0% less than the bearing capacity of the pyramidal pile (with the dimensions of the upper section 10.0 × 10.0 cm and the lower section 6.7 × 6.7 cm);
- the bearing capacity of the test piles increases by 1.22-1.53 times with an increase in the length of the pyramidal part from 33 cm to 133.2 cm.

Calculation formulas

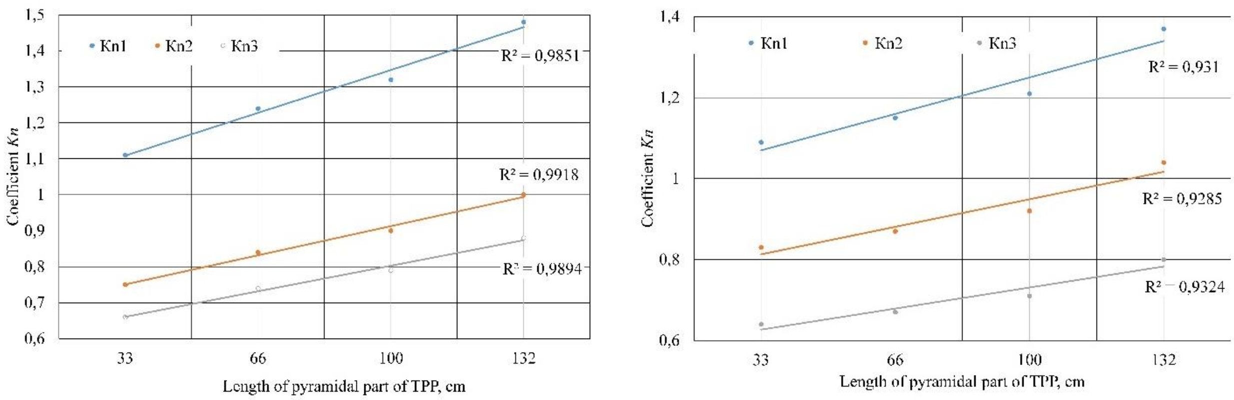
The data presented in Tables 6 and 7 are mathematically described by the following linear function:

$$K_n = al + b, \quad (3)$$

where: K_n - coefficient of relative efficiency for the bearing capacity of piles; l – length of the tapered (pyramidal) part of the TPP; a and b – coefficients taken according to Tables 9 and 10.

Tab. 8. Coefficient values of a and b in K_n (3) at pile settlement at 20 mm and 40 mm

Relative efficiency coefficients for bearing capacity of piles	Coefficient values		The value of the accuracy of the approximation (R^2)
	a	*b*	
at 20 mm			
K_{n1}	0,119	0,99	0,985
K_{n2}	0,081	0,67	0,991
K_{n3}	0,071	0,59	0,989
at 40 mm			
K_{n1}	0,09	0,98	0,931
K_{n2}	0,068	0,745	0,928
K_{n3}	0,052	0,575	0,932



a) at the settlement of 20 mm *b) at the settlement of 40 mm*

Fig.6. K_n coefficient values versus length of tapered part of TPP

The data presented in Table 8 are mathematically described by the following linear function:

$$K_{gp} = kl + p, \quad (4)$$

where: l - length of the tapered (pyramidal) section of the TPP; k and p - coefficients are taken according to Tab.9.

Tab. 9 The values of the coefficients k and p in the formula (4)

Horizontal relative efficiency ratios	Coefficient values		The value of the accuracy of the approximation (R^2)
	k	*p*	
K_{gp1}	0.202	0.945	0.963
K_{gp2}	0.093	0.455	0.959
K_{gp3}	0.089	0.42	0.950

The test results presented in Table 9 allow obtaining the following correlation dependences

$$F_{TPP} = F_{gp1} + \Delta_F, \quad (5)$$

$$F_{TPP} = F_{gp2} - \Delta_F, \quad (6)$$

$$F_{TPP} = F_{gp3} - \Delta_F, \quad (7)$$

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

where: F_{gp1}, F_{gp2}, F_{gp3} - bearing capacity, respectively, of the model of a prismatic pile with a cross-sectional area of 6.7×6.7 mm, a model of a prismatic pile with a cross-sectional area of 10.0 × 10.0 mm and a model of a pyramidal pile with a cross-sectional size in the upper part of 10.0 × 10.0 mm, in the lower part - 6.7×6.7 mm**,** N; Δ_F – the difference between the values of the bearing capacity of the test and control piles, N; *g* and *d* - coefficients taken from the Table 10; *l* – the length of the tapered (pyramidal) section of the TPP.

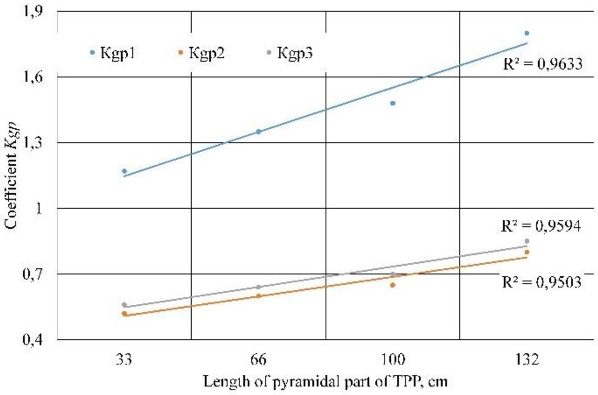


Fig.7. K_{gp} coefficient values versus length of tapered part of TPP

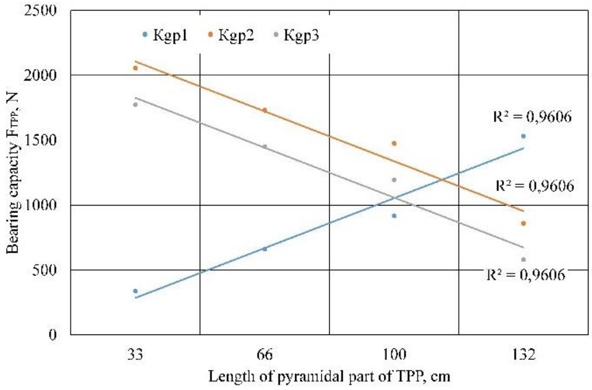


Fig.8. Bearing capacity of piles F_{TPP} versus length of a pyramidal part of TPP

Table 10. The values of the coefficients g and d in the formula (8)

The quantity of Δ_F in the formula	Coefficient values		The value of the accuracy of the approximation (R^2)
	g	*d*	
(5)	384	98	0.960
(6)	-384	2210	0.960
(7)	-384	2490	0.960

The presented data allow us to make the following conclusions:

- a calculation formula has been obtained that allows us to determine the experimental data of the relative efficiency coefficients for the bearing capacity of the TPP under the action of a pressing static load;
- formulas are proposed for the calculated determination of the bearing capacity of the TPP under the action of a horizontal static load relative to a similar power parameter of the control piles;
- the obtained formulas are distinguished by a fairly high (from 92 to 99%) reliability of the calculation results.

Conclusion

The following main conclusions can be formulated based on the presented results of experimental studies of the tapered-prismatic piles on sandy loam:

- with an increase in the length of the pyramidal section of the TPP, the energy costs for their immersion is increased, and their bearing capacity (specific bearing capacity) also increases under the action of pressing and horizontal loads;
- depending on the length of the pyramidal section of the TPP, in comparison with prismatic and pyramidal piles, have both greater and lesser bearing capacity (specific bearing capacity);
- for the calculated determination of the bearing capacity of the TPP under the action of a horizontal load, formulas were obtained that ensure the high reliability of the calculation results.

Thereby, the length of the pyramidal part of the TPP significantly affects the energy consumption of their driving, immersion and resistance to the action of an indentation and horizontal load. This is explained, in our opinion, by effective compaction and a significant manifestation of repulsive soil forces under the inclined edges of the tapered (pyramidal) part of the TPP when they are grounded into the soil strata.

The obtained results have practical value during field testing of TPP with dynamic and static loads for their use in the area of civil engineering and hydraulic structures.

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