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FEATURES OF THE COMBINED IMPACT OF DRIVEN COMPACTION PILES AND THE ASSOCIATED SUBSOILS

ОСОБЛИВОСТІ СПІЛЬНОЇ РОБОТИ ЗАБИВНИХ ПАЛЬ УЩІЛЬНЕННЯ З ОСНОВОЮ

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The article describes the main features of the combined impact of the driven compaction piles and the associated soil strata. The compaction piles can be pyramidal, machine-driven, or self-expanding when being driven. The peculiarities of the nature of work related to the compaction of the soil strata when the piles are driven. The compaction of the soil strata provides the additional load-bearing capacity and supports the transferred external load. Subsoils and the quantitative assessment of their building properties are evaluated based on the nature and inherent conditions of earth strata formations, and mineralogical and salt compositions. Changes to the fore-said properties depend on the degree of humidity, the peculiarities of soil structure, the location of individual particles, and the resistance to external loads. Internal resistance to compaction is determined by the bulk density of dry soil ρ_d during the deformation. The abnormalities related to the working of the subsoils associated with driven compaction piles correlate to the transfer of the external load by the lateral surface of the piles to the pre-compacted soil during the course of immersion. In the case of machine-driven batter piles, a compacted soil core between the inner edges of the surfaces of the elements acts in tandem with the pile. In this scenario, the density of the soil composition reaches its maximum value.

The results of the field tests proved, that self-opening batter piles perceive 1.2-1.3 times more resistance than pyramidal ones of the same volume. The use of driven compaction piles does not apply to foundations composed of permafrost soils, unstable landslide areas, and to undermined areas.

The practice of introducing compaction-driven piles into construction has shown significant savings in building materials, and a reduction in the construction time of residential, public, and industrial buildings.

У статті викладено основні положення спільної роботи з основою забивних паль ущільнення (пірамідальних, козлових, що саморозкриваються при забиванні). Особливості їх роботи полягають у створенні під час занурення навколо себе ущільненого об'єму ґрунту, на який передається зовнішнє навантаження.

Кількісна оцінка будівельних властивостей ґрунтів основи виконана з урахуванням природи та генетичних умов їх утворень, мінералогічних та сольових складів. Зміна цих властивостей залежить від ступеня вологості, особливості їхньої структури, розташування окремих частинок, їх опору зовнішнім навантаженням. Внутрішній опір ущільненню визначається щільністю сухого грунту ρd при деформації.

Особливості роботи забивних паль ущільнення з основою полягають у передачі зовнішнього навантаження бічною поверхнею паль на попередньо ущільнений ґрунт при зануренні.

У козлових палях в роботу включається також ущільнене ядро ґрунту між внутрішніми гранями поверхонь елементів, щільність складання ґрунту якого досягла свого граничного значення. Як показали натурні випробування, козлові палі, що саморозкриваються, сприймають у 1.2-1.3 рази більший опір у порівнянні з пірамідальними, однакового обсягу.

Результати досліджень показали, що забивні палі ущільнення рекомендують застосовувати в піщаних, піщано-глинистих і насипних грунтах без вмісту органічних включень з віком насипу не менше 10 років. Грунти повинні мати середню щільність складання сухого грунту $\rho_d \approx 1.45\text{-}\ 1.60$ *г/см*^{3}*. Застосування забивних паль ущільнення не поширюється на основи, складені вічномерзлими ґрунтами, на нестійкі зсувні ділянки та на території, що підробляються. Застосування забивних паль поширюється на фундаменти житлових будинків, промислових будівель та інженерних споруд з монолітним або збірним ростверком зі значними вертикальними, горизонтальними та моментними навантаженнями.*

Практика впровадження забивних паль ущільнення у будівництво показала значну економію будівельних матеріалів, скорочення термінів будівництва житлових, громадських та промислових будівель.

Keywords: subsoils, compaction driven piles, pyramidal, batter piles, pile driving unit head, bulk density of dry soil, compaction zone, structural strength of soils.

Ключові слова: забивні палі ущільнення, пірамідальні, козлові палі, оголовок палезабивного агрегату, щільність сухого ґрунту, зона ущільнення, структурна міцність ґрунтів.

Introduction. Sometimes a person uses in his practice an idea borrowed from nature, drawing inspiration from the wonder of flora's complex root system which is able to withstand external loads (own weight, wind, climatic fluctuations, floods of territories).

The robustness offered by the beauty of nature has been leveraged in the design of the underground support system of buildings and structures, in construction practice. The effective utilization of driven compaction piles (pyramidal, machine-driven piles) is a classic example of this idea, resulting in the capability to withstand significant external loads (vertical, horizontal, moment).

A quantitative assessment of the properties of the soils that make up the foundation cannot be objectively performed without considering the nature and mechanism of the combined impact of pile foundations and their subsoils, formed under certain native conditions. This aspect wields a considerable influence on the configuration of the building properties of foundation soils.

The reactive properties of soils or their internal resistance to compaction are determined by the density of the dry soil ρ_d, and its mineralogical and salt composition. Changes to these properties depend on the degree of moisture, as well as the features of the soil structure. The structural resistance of the interparticle bonds to compaction is essentially established by the above-mentioned properties.

The nature of internal forces is manifested in the action of the reactive resistance of the soil to compaction during deformation. The soil particles continue to move till the forces of compaction acting on them are completely overcome by the internal reactive resistance.

The analysis of the building properties of soils based on different operating conditions (compaction, changes in moisture, temperature, heterogeneity of the layers) is intrinsically based on the bulk density of the dry soil - the governing scientific parameter. This is essential because bulk density defines soil stability in the most unfavorable conditions.

When designing pile foundations made of prismatic piles, during driving, the load is transmitted mainly by the tip of the pile to uncompacted high-density soil, as well as due to friction along the lateral surface.

Purpose of the study. The purpose of the article is to conduct a comparative analysis of the mechanism of operation of compaction-driven piles, presented in the form of pyramidal and batter piles; confirm the conclusions obtained through experimental studies and formulation of recommendations for the appropriate use of compaction-driven piles.

Analysis of the latest sources and statement of the problem. This article is based on the results of the dissertation research of Plakhotny G. [1].

Interest in the usage of batter piles appeared at the beginning of the last century, however, even now batter piles are being improved and widely studied by scientists. The comparative analyses of [2] showed that the batter piles possess lower distribution of dynamic axial load and higher dynamic bending moment in a pile along the depth as compared to the vertical pile. The dynamic response of cast in-situ reinforced concrete batter piles and pile groups constructed in the silty sand investigated through field tests was presented in [3]. In the study [4], the dynamic response of pile foundations in dry sandy soil excited by two opposite rotary machines was considered experimentally. Another experimental study on vertical batter piles and pile groups under uplift load conditions in non-cohesive sub-soil was presented last year in [5]. Features of the batter piles' design according to foreign standards are outlined in the work [6]. On the territory of Ukraine, the design and calculation of piles is carried out in accordance with the State Construction Standards of the National Building Code [7,8] and the results are presented in many works of Ukrainian research scientists [9,10].

Methods of the Study. *Impact of Pyramidal Piles:*

When pyramidal piles are driven, a large volume of compacted soil is formed around the lateral surfaces of the pile edges. Increasing the conicity of a pyramidal pile to 12-15^0 increases the load resistance by 2.0-2.5 times compared to prismatic piles of equal volume.

When a pyramidal pile is immersed in the ground, the weight of the hammer is selected depending on the density of the soil and the weight of the pile. With a density of $\rho_d \geq 1.45$ g/sm^3, the weight of the hammer should be 2.5 times greater than the weight of the pile, while with $\rho_d \leq 1.45$ g/sm^3, the suggested hammer weight is just about twice the pile weight.

The high resistance offered by the piles to loads can be attributed to the support provided by the compacted sub-soil around and under the pile.

Pyramidal piles transfer a small pressure of 0.7-1.5 kg/sm^2 to the soil compacted during while being driven with a large area of their lateral surface. The location of the deformation zone within the area of the compacted volume determines the value of the permissible settlement of the pile and its high resistance to external loads.

Impact of Machine driven batter (inclined) piles:

Driven compaction piles include machine-driven batter piles that unfold when driven. These foundations can consist of a different number of pile elements (Fig.1) which, when driven into the ground, create a stable support of a large area at the level of the footing. Piles come in various lengths with varying cross-sections of the head They can be composed of prismatic, wedge-shaped, or pyramidal elements. Pyramidal elements have a beveled inner edge. For driving batter piles, standard piling equipment with a special head is used.

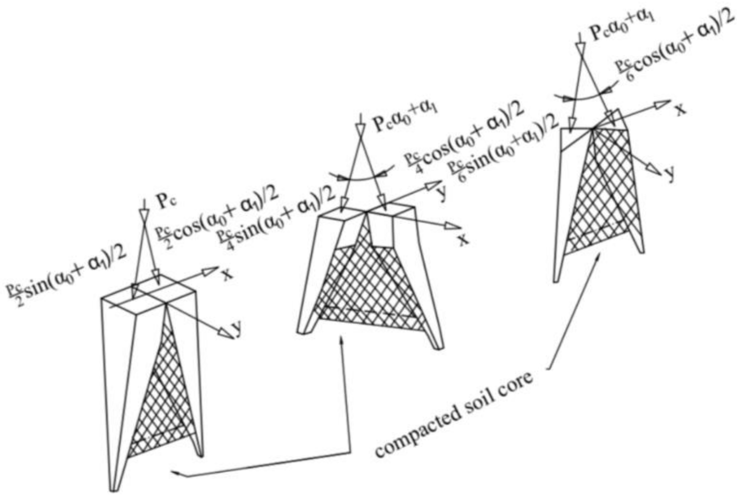


Fig. 1. Basic design diagrams of batter piles, consisting of 2, 4, or 6 elements

Opening of the pile elements occurs during driving, while a compacted soil core is formed between the beveled edges, which has a wedging effect on the elements. The opening angle (Fig.2) depends on the angle of inclination of the inner edges, the total length of the pile, and the density of the soil.

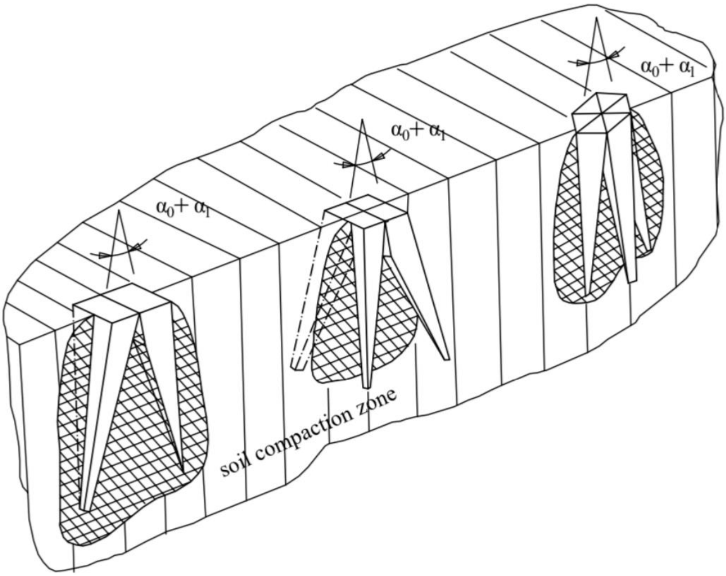
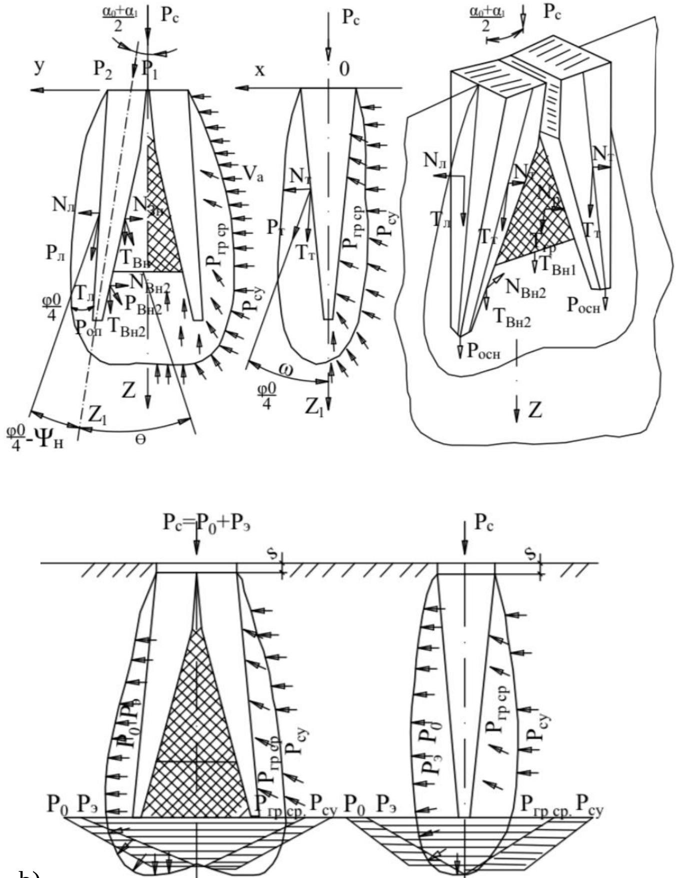


Fig. 2. Nature of the compaction zone formation at the base of the batter piles

Soil compaction also occurs from the outer edges of the elements and depends on the sharpening angle, the ratio of the distance from the outer edge of the element to the axis of the battered pile in soils of different densities. An increase in the sharpening angle to 20^0 or more may be advisable at low soil density ($\rho_d \leq 1.45$ g/cm^3). With an increase in the density of the soil, the taper angle of the element can be reduced to 15-20^0 per 1m of length. The presence of an angle between the edge and the vertical surface causes the work of the pile to "thrust" like a bulk wedge creating a volume of compacted soil. The average value of soil density within the soil core is 1.75 g/cm^3, and within the compaction zone around the pile is 1.60 g/cm^3.

The vertical load is transferred to the surrounding pile, and compacted during driving, through the side surface, the pile base, and the soil core. In this case, a deformation zone is formed within the compacted volume of the soil (Fig.3). The boundary of the deformation zone with increasing load moves from the edge of the pile to the boundary of the compaction zone, which is also confirmed by the study of the work of the pyramidal pile.



a) b)

Fig. 3. (a) Scheme of external load transferring by a battered pile to the associated subsoils; (b) and redistribution of effective and reactive pressure during settlement

Results of the study. In Odessa, more than 200 buildings with varying no. of floors in various soil conditions were built on pyramidal piles. About 60 thousand pyramidal piles of various geometric shapes were driven into the ground [10]. Unique experiments with pyramidal piles were carried out in Yaroslavl at the site of the Diesel Equipment Plant (YADEP). As a result of testing 9 single piles having a load of 1500-1800 kN, the settlement was 5-7 cm. In a 5-pile foundation with a load of 7500 kN, the settlement was 5.0 cm and in a 9-pile foundation with a load of 1200 kN, the stabilized settlement was 7.0 cm.

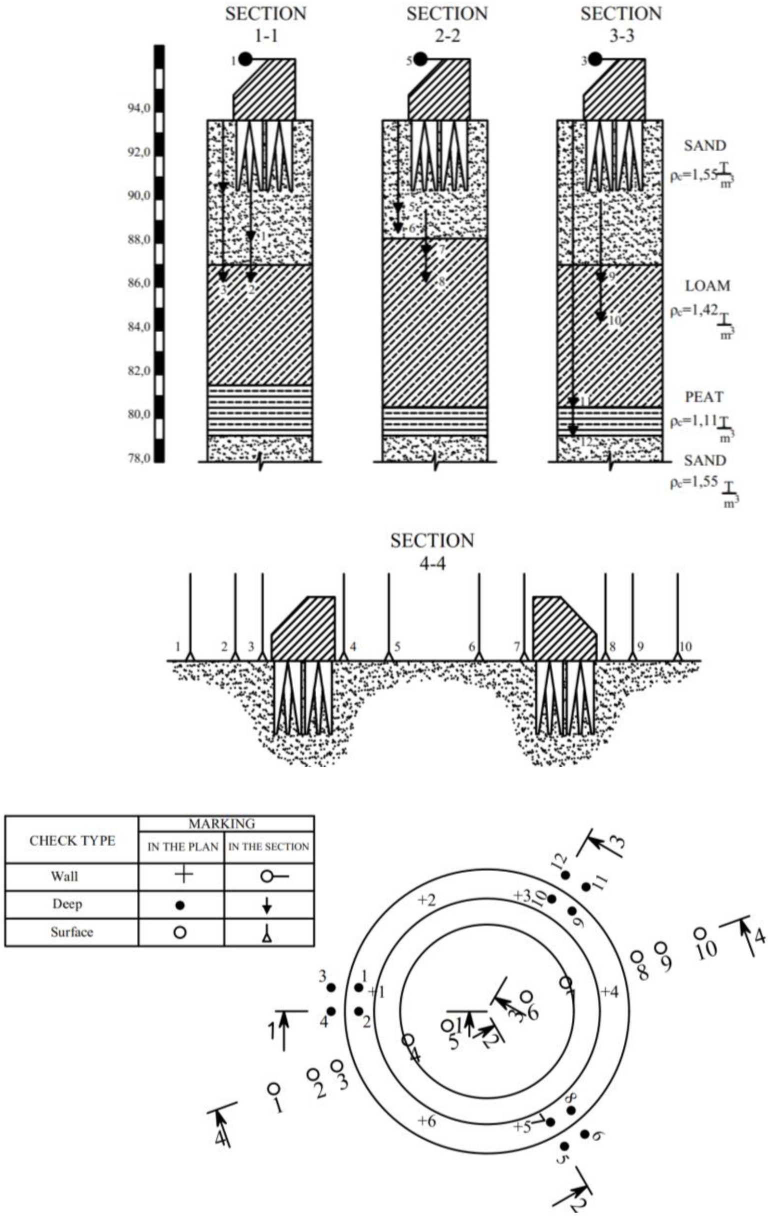


Fig. 4. Layout of depth and surface marks at the base of the annular pile foundation of the smoke pipe H = 80m at YADEP

The tests were carried out in a layer of dense sand, underlain at a depth of 6.0m by a layer of peat, 3.0m thick. Depth marks (Fig. 4) embedded on the top and bottom of the peat showed no sediment, which confirms the fact that the pyramidal piles work to «thrust» as single piles and do not transmit pressure to the underlying weak layers. The results obtained were implemented in the construction of YADEP facilities, which made it possible to reduce the construction time by 8 months and save 1.0 million rubles.

As shown by field tests, self-opening batter piles perceive 1.2-1.3 times more resistance than pyramidal ones of the same volume. When erecting a pile ring foundation for a chimney H = 80m at the YADEP site, 16 batter piles were used, consisting of 6 separate elements (Fig.5).

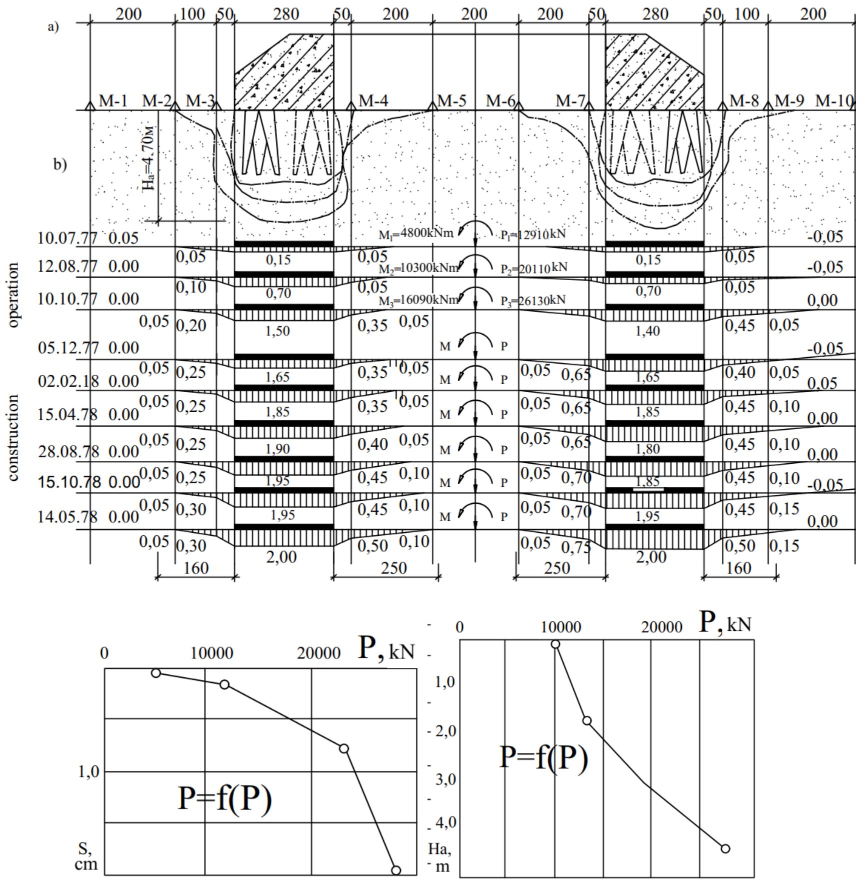


Fig. 5. Results of observations of the settlement of the annular pile foundation during the construction and operation of the smoke pipe at YADEP

When testing a single pile, the stabilized settlement was 5.0 cm at a load of 3220 kN. The loads on a separate batter pile in the project were: vertical – 1850 kN; horizontal – 220 kN; pulling out - 17 kN.

In a residential building (Pereslavl Zalessky), a strip foundation of batter two-element piles was used. A load of 1600 kN was laid on one pile in the project.

During the construction of the iron casting workshop in Tutaev, the load on 1 pile in the pile foundation of 5 batter piles in the project was 1500 kN. The total economic effect of the introduction of batter piles was about 300 thousand rubles. When examining the combined impact of single batter piles and individual piles in the structure of the foundations (Fig.6), it was revealed that a single pile works separately in the foundation with a step between the piles $l \geq$ 2.5d (d is the width of the pile in the head).

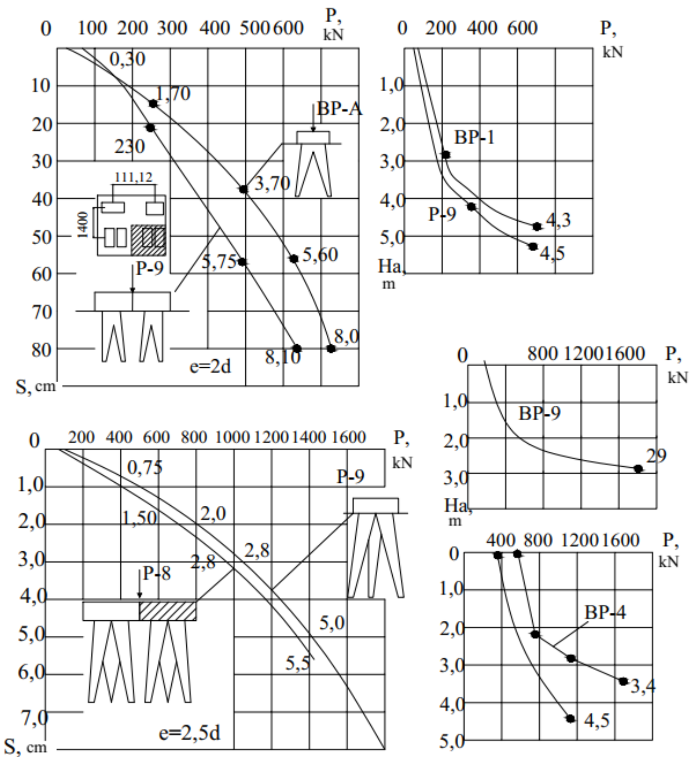
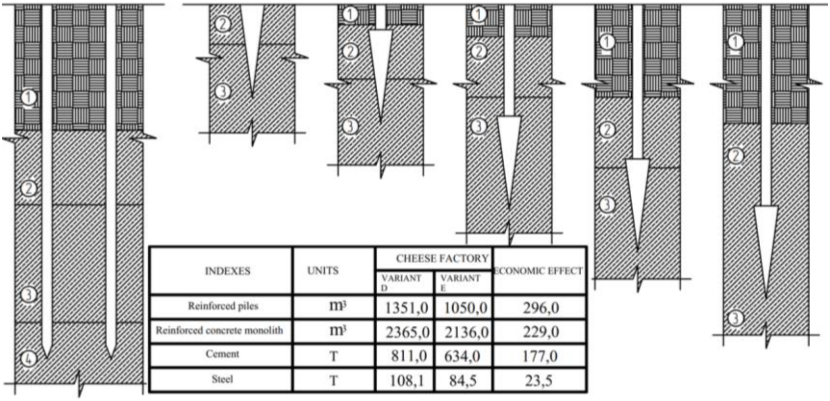


Fig. 6. Comparison of the impact of single batter (inclined) piles and individual piles in foundations

In the city Pereslavl Zalessky, the construction site of the cheese factory had a geological slope of about 4m. The option with the erection of foundations from prismatic piles with a length of 12m was replaced by a pile foundation of pyramidal piles with posts of different lengths (1-4 m), which reduced the construction time and gave an economic effect (Fig.7).



INDEXES	UNITS	CHEESE FACTORY		ECONOMIC EFFECT
		VARIANT D	VARIANT E	
Reinforced piles	m³	1351,0	1050,0	296,0
Reinforced concrete monolith	m³	2365,0	2136,0	229,0
Cement	T	811,0	634,0	177,0
Steel	T	108,1	84,5	23,5

Fig. 7. Pile foundation of pyramidal piles with posts of different lengths

Conclusion. Driven pile compaction is recommended for use in sandy, sandy-clayey, and bulk soils without organic inclusions with an embankment age of at least 10 years. The soils should have an average bulk density of dry soil $\rho_d \approx$ 1.45-1.6 g/cm^3. The use of driven compaction piles does not apply to foundations composed of permafrost soils, unstable landslide areas, and to undermined areas. The use of driven compaction piles extends to the foundations of residential houses, industrial buildings, and engineering structures with monolithic or prefabricated grillages with significant vertical, horizontal, and moment loads.

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