Збірник наукових праць. Серія: Галузеве машинобудування, будівництво

Academic journal. Series: Industrial Machine Building, Civil Engineering

http://journals.pntu.edu.ua/znp

https://doi.org/10.26906/znp.2018.51.1297

UDC 624.131.524.4

Experience of using Odessa region limestones as foundation base

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The characteristic properties of limestone-shell rock used as foundation base, including shear resistance transformation into friction resistance, are described. The main provisions of the method for determining piles bearing capacity using limestone mechanical characteristics dependence on the tensile strength under uniaxial compression in Odessa region. The results of limestone-shell rock full-scale tests by bored piles are presented. Experimental values of piles bearing capacity are compared with the values obtained by calculation using different methods.

Keywords: limestone-shell, bearing capacity, bored pile

Досвід використання вапняків одеського регіону як основи фундаментів

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Установлено, що при будівництві висотних будівель в Одесі часто використовують фундаменти з буронабивних паль, які занурюють у вапняк-черепашник та не прорізають усієї його товщі. Заглиблення паль у менш міцні меотичні глини не доцільно, оскільки навантаження від будівлі палями передається на весь масив вапняку. Визначено, що при розрахунку таких фундаментів виникають труднощі, оскільки вапняк-черепашник Одеського регіону не є скельною породою, а в нормативних документах відсутні дані для визначення несучої здатності буронабивних паль у вапняку як паль тертя. Екс**периментально доведено, що за результатами статичних випробувань буронабивних паль у вапняку-черепашнику їх несуча здатність значно вище значень аналітичних розрахунків за існуючими нормативними документами у вигляді паль-стійок, оскільки середнє значення межі міцності при одновісному стисненні вапняку малої міцності зазвичай становить R_c = 0,5... 1,0 МПа. Виявлено, що завданнями цих досліджень є визначення несучої здатності буронабивних паль у вапняку-черепашнику шляхом проведення статичних випробувань натурних зразків, а також порівняння отриманих результатів з аналітичними рішеннями різними способами для обґрунтування проектних рішень. Для розв’язання поставлених завдань застосовано експериментальні та розрахункові методи, як стандартні, так розроблені за участю авторів. З’ясовано, що комплексні дослідження дозволили визначити несучу здатність і допустиме навантаження на буронабивні палі шляхом проведення статичних випробувань та аналітичного розрахунку за нормативними документами й запропонованою методикою. Установлено, що результати розрахунку запропонованим методом дають хорошу збіжність з результатами статичних випробувань.

Ключові слова: вапняк-черепашик, несуча здатність, буронабивна паля

Introduction. While constructing high-rise buildings in Odessa, foundations from bored piles are often used, which are dipped in limestone-shell or cut it and deepen piles ends into the meiotic clay. Difficulties occur while calculating such foundations as far as limestone-shell rock is nor hard rock in Odessa region, and according to the indices of its physical and mechanical properties, cannot refer to rock or semi-rock, and consequently piles stopped in it cannot be regarded as bearers. Normative documents lack the data for determining lime stones resistance occurring under considering bored piles work as hanging piles. Peculiarities of these rocks are noted by other authors as well [1, 5, 7]. According to results of bored piles static testing in limestone-shell rock, their bearing capacity is considerably higher than those of analytical calculations under their work condition as bearing pile, since average value of strength limit under low strength limestone single-walled compressions usually equal to R_c = 0,5... 1,0 MPa.

Aim and objective. The main tasks of the present studies are to determine limestone-shell rock resistance on lateral surface and under bored piles heel according to the results of data obtained from static testing of models and full-scale samples; comparison of the results obtained with analytical solutions, and development of recommendations for their correction.

Study object and methods. The object of research is limestone-shell rock of Odessa region. To solve the tasks set for determining bearing capacity of bored piles in limestone-shell rock, experimental and calculating methods were used, including both standard ones and those developed by the authors.

Study results. Geological structure of the Black Sea plateau earth cover is represented by sediments of Quaternary and Tertiary age. Under the complex loess rocks with 6 to 23 m thickness there is red-brown clay underlain by Pontian limestone of Neogene.

Figure 1 shows the columns of the engineering-geological structure of some sites within Odessa city, where studies of pile foundations partially or completely buried in limestone-shell rock were carried out.

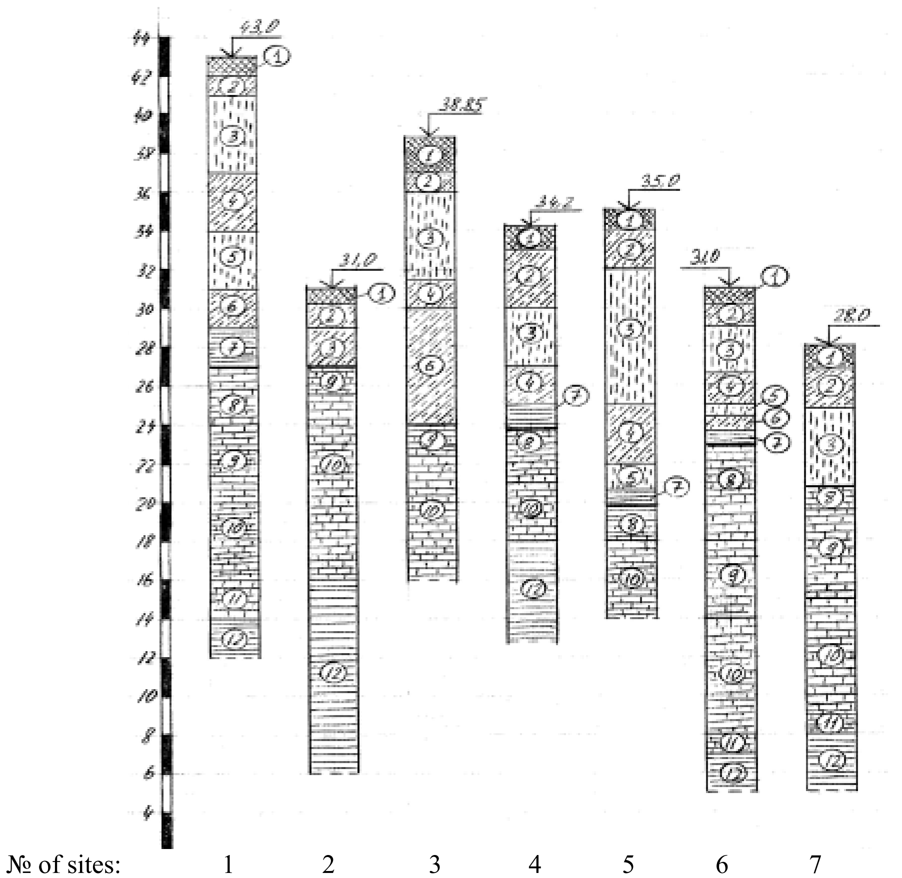

Figure 1 – Experimental sites engineering-geological columns:
1 – Lastochkina street (Odessa National Theater of Opera and Ballet);
2 – Primorsky Boulevard (section of the retaining wall); 3 – Zhukovsky street, 18 (regional archive);
4 – Pushkinskaya street, 9 (Odessa Museum of Western and Oriental Art);
5 – 15 Bolshoi Fountain station (cottage town); 6 – Genuezskaia street, 1 (group of high-rise buildings);
7 – Polskaia street, 10 (multi-storey office building)

The limestone layer of Pontic Stage has a rather complex and volatile structure, both in vertical and horizontal directions. The thickness of Pontic limestone can be divided into four layers. The first – the lowest layer (EGE-11) – is represented by slab limestone with 0.2 ... 1.0 m thickness. The second layer (EGE-10) is represented by a uniformly cemented limestone-shell rock ("sawn" limestone) with 4.5 ... 7.9 m thickness. Within this layer there are workings, so-called "catacombs". The third layer (EGE-9) is made up of strongly recrystallized limestone-shell rock. The fourth – the uppermost – layer (EGE-8) is predominantly represented by plate-clastic limestone. The total thickness of the third and fourth layers is equal to 5.0 ... 5.6 m. Placed above, there are loess and loess-like loams of different consistency, which are underlain by red-brown clay. Their thickness reaches 12 ... 16 m. Quaternary aquifer is widespread in loess rocks. It was formed mainly due to leaks from water-bearing communications.

Physical and mechanical properties of Pontic limestone depend upon many factors, including their fracturing. Limestone resistance to uniaxial compression varies widely. Characteristic feature is increase in their strength in the direction of watersheds and reduction in strength near large erosion cuts. In some parts of Odessa territory, strength of limestone in dry condition varies from 0.5 to 2.0 MPa. In condition of water saturation, limestone strength is reduced to 1.5-2 times.

Soil layering analysis and experience of using piles in Odessa region show that the most effective foundations while using limestone shells are drill piles, which do not completely cut its thickness. Sloping all the limestone thickness with piles and dipping them into less durable meiotic clay is not feasible, since load from the building is transferred over to the whole massif of limestone. Limestone layers availability as a cemented hard layer in the deformable zone of the base determines formation of a complex stressed state in it, in particular, concentration of tangential stresses. The problems occur due to possible pushing the thickness of limestone along the surface, forming a prism over the pile outer contour of slab-pile foundation [6]. Due to the limestone existence in the weakened zones, the inhomogenuity of its properties, the presence of natural cracks, pushing on one side of the foundation may take place, which lead to occurrence of an excessive roll and significantly impede the further building operation.

Experimental studies have established that when immersing drill piles in limestone-shell, along the lateral surface of the trunk, two types of resistance arise: resistance to structural bonds destruction, which transforms into frictional resistance after the «breakdown». Fracture resistance occurs under stresses exceeding structural strength of f_{str} shear, which is the ultimate shear strength. Friction resistance f occurs on the surface formed after the «breakdown». This phenomenon should be considered when determining drilling piles bearing capacity.

According to laboratory studies conducted earlier [3, 4], «breakdown» occurs when the barrel of the pile is moved to in average of 0.3 mm.

The average weighted value of shear resistance reduction coefficient along the trunk according to results of the studies conducted is 0.69, with the placement of piles across the layer.

Table 1 – Results of limestone-shell research by models of piles, located across the layers

№ Serial	Tests number	Resistance on the side surface		Pile side surface resistance decrease coefficient γ_{cf}
		before the breakdown f_c, MPa	after the breakdown f, MPa	
1	8	0.67	0.36	0.54
2	8	0.45	0.36	0.80
3	8	0.38	0.23	0.61
4	8	0.42	0.26	0.62
5	8	0.44	0.37	0.83
6	8	0.52	0.41	0.74
Average	**48**	**0.48**	**0.33**	**0.69**

At one of the objects in Odessa, limestone testing was carried out with six drill piles.

Pile basis is made of dark yellow, recrystallized, «plated», fractured with clay filler from very low to low strength limestone-shell (Fig. 2).

According to hydrogeology, the territory is characterized by lack of Quaternary and Pontic aquifers. The results of limestone testing with drilling Ø600 mm piles at construction site of the 1st stage are shown in Fig. 3, and the second line in Fig. 4. The exterior of the test installation is shown in Fig. 5.

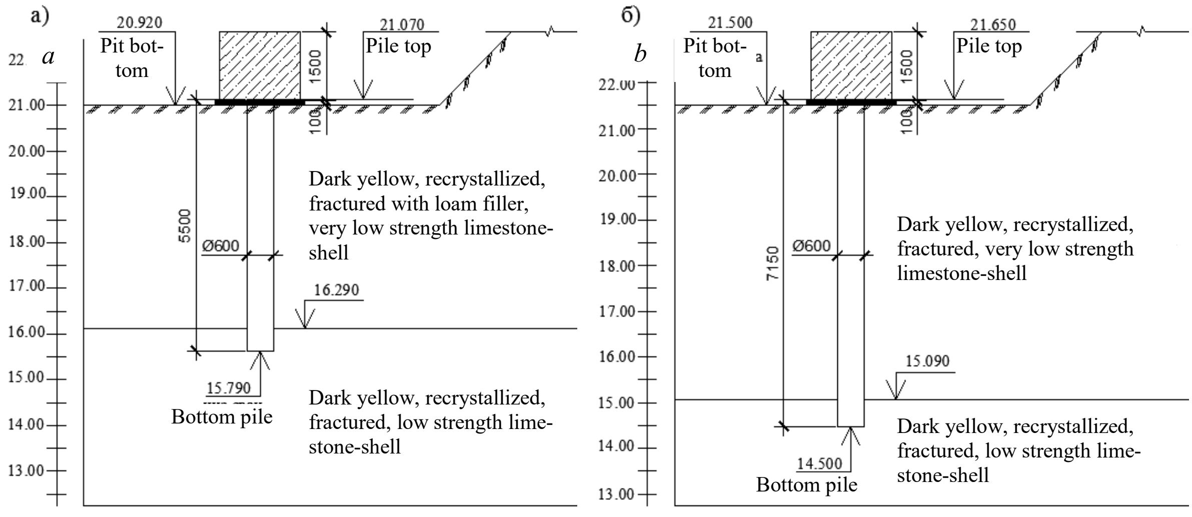

Figure 2 – Binding of piles to engineering-geological section:
a – 1st stage of construction (C-1, C-2 and C-3); *b* – 2nd stage of construction (P-4, P-5 and P-6)

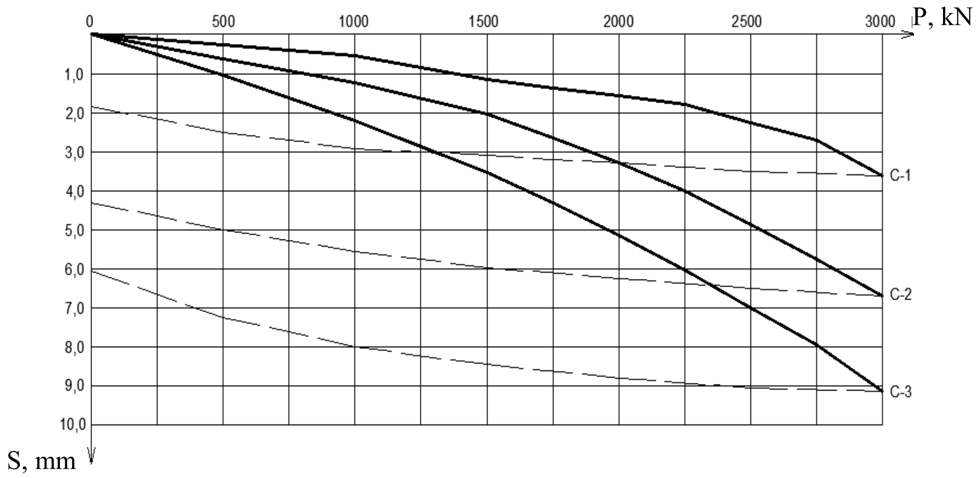

Figure 3 – Graphs of C-1, C-2 and C-3 piles moving from vertical load

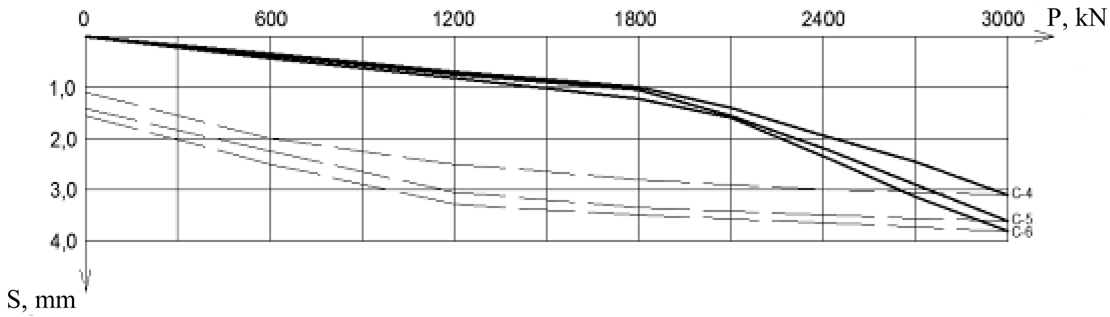

Figure 4 – Graphs of C-4, C-5 and C-6 piles moving from vertical load

Figure 5 – Fragment of soils testing with bored piles

The recommendations for calculation of bored piles partially or completely buried in a layer of limestone-shell rock are given. The H.3.1 formula [2] is used as a basis for calculation based on the vertical indentation load. This formula included coefficients and characteristics that determine bored piles work features in limestone-shell.

$$F_d = \gamma_c (\gamma_{cR} RA + u \sum \gamma_{cf} f_{c,i} h_i), \qquad (1)$$

where γ_c is pile work conditions coefficient; in case of piles being supported by dusty clay soils with moisture content S_r <0.9 and on loess soils γ_c = 0.8, in other cases γ_c = 1.0;
γ_{cR} – soils work conditions coefficient under pile bottom; γ_{cR} = 1;
R – calculated soil resistance under pile lower end, supported on limestone-shell rock, equal to its structural strength p_{str} and taken according to the graph in Fig. 6, in other case – according to Tab. H.2.1 [2], kPa;
A – pile support area, m^2;
u – perimeter of pile shaft cross section shaft, m;
γ_{cf} – coefficient of soil working conditions along pile lateral surface within limestone-shell rock, taken as γ_{cf} = 0.65, in other cases – according to Tab. H.3.1 [2];
$f_{c,i}$ –ultimate resistance to i-th soil layer shift along pile within limestone-shell rock lateral surface, $f_{c,i} = f_{str}$ is taken from the graph of Fig. 6, in other cases $f_{c.i} = f_i$ according to design resistance of the i-th layer of soil on the pile lateral surface, kPa, taken from Tab. H.2.2 [2].

Figure 6 shows correlation of limestone-shell rock strength parameters from the ultimate strength to uniaxial compression in the air-dry and water-saturated state, which were used while determining piles bearing capacity according to the proposed procedure.

Table 2 represents the results of tested piles bearing capacity determining as a result of full-scale tests, and also according to the current normative document [2] as pile-pillars and by the method proposed by the article authors and described in detail in [3].

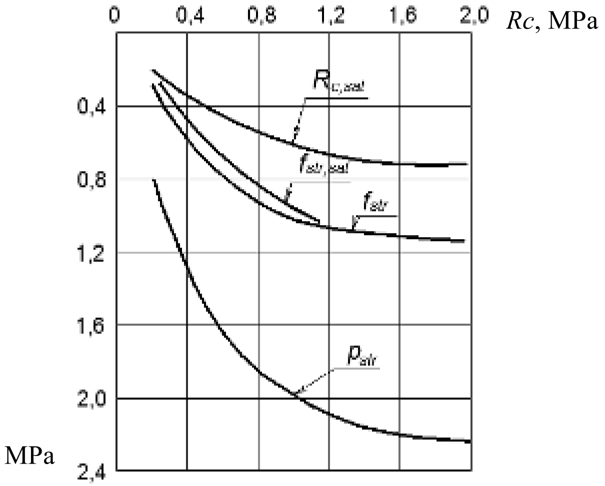

Figure 6 – Correlation dependencies of sawn limestone-shell rock limit values resistance parameters from the ultimate strength to uniaxial compression

Table 2 – The results of bored piles bearing capacity determining with different methods

Pile number	Piling depth Ø600 mm in limestone, m	Bearing/calculated bearing, kN, defined according to:		
		DBN V.2.1-10-2009	Methodology suggested	Testing results
C-1,C-2, C-3	5.50	1050/750	4030/2880	3000/2500
C-4,C-5, C-6	7.15	1340/947	5570/3980	3000/2500

Conclusion. The completed complex studies enable to establish bearing capacity and permissible load on the bored pile in limestone-shell rock by carrying out static tests and analytical calculations of the normative documents and the proposed methodology. The calculation results by the method suggested are convergence with static tests results. Convergence increases with the approach of displacements during testing to limit values.

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