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Original Research Article

INFLUENCE OF THE STATIC LOADING OF A RAFT UNCONNECTED TO A PILE ON THE PILE DISPLACEMENTS TESTED IN FIELD CONDITIONS

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Abstract

We present the results of a static pile-raft interaction test in field conditions. The pile and the raft were unconnected. The static loading on the raft affected the displacements of the pile due to the skin friction. The displacements were also observed for another pile, placed at the 3-metre distance.

Keywords: pile foundation, pile unconnected with a raft, skin friction forces

1. INTRODUCTION

The role of a raft in the standard understanding of a pile foundation is closely related to the accumulation of some reserves of the bearing capacity of foundations and the unused potential of soil bases below the raft. The neglect of those resources leads to an increase in the total cost of the building and to the irrational usage of urban areas.

The application of a raft and the regulation of a stress-strain state of the base of a pile foundation are widely used in the international practice [1, 2, 7]. This allows maximal loading of the soil base. In other words, higher buildings can be erected, or pile foundations with smaller sizes can be designed.

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The problem of interaction between pile foundation, soil base and buildings is becoming more and more important for geotechnical construction.
In a pile-raft foundation, the raft starts to respond after reaching the bearing capacity of the pile shaft and base. Thus, it is advisable to preload a raft at the first stage (before the pile foundation is installed) in order to enhance the role of the raft in the bearing capacity of a pile foundation.
The role of the raft in the pile-raft foundation can only be tested separately in in field tests. In this case, the influence of the loading of the raft at the first stage on the displacement of a pile is of great importance. After the raft has been loaded, the pile and the raft need to be additionally connected.
The process of the gradual connection between the raft and the pile leads to additional displacements of the pile due to negative skin friction. According to the literature, this process needs to be further considered and researched [3, 4, 5].
The previous laboratory tests [6] confirmed the formation of zones with additional friction forces along a pile. The forces cause the pile displacement due to the loading of a raft unconnected with a pile. This research was based on these assumptions. The paper includes the analyses of the influence of the static loading of a full-scale raft (unconnected with a pile) on the pile displacement in field tests. Additionally, the dependence of pile displacements on a loaded raft displacement were determined.

2. GENERAL CHARACTERISTIC OF A SITE. PREPARATION TO THE EXPERIMENT

Field tests were conducted on a construction site of a three-section building in a settlement of Slobozhanske, the Dnipropetrovsk region. The engineering-geological exploration was carried out by a licensed firm, and its results were used as input data in the realization of full-scale experiments.
The tested foundation was erected in the excavation. The bottom of the excavation reached the EGL 3 (soil Engineering Layer 3), including fine-grained sands. The EGL 3 has interlayers of loams in its top part and water-saturated sands at depths of 2.6-3.2 m. Underneath the EGL3 there is a layer of the EGL 4 which consists of light sandy loams of soft consistency. The next (in the downward direction), there is the EGL 5, represented by medium-sized arenaceous loams with a tough consistency. The EGL 6 includes fine-grained, water-saturated sands, with medium-grained sand as the underlying layer.
Physical-mechanical characteristics of soil on the testing site are given in Table 1. The underground water table was found at the depth of 2.6-3.2 m.

Table 1. Physical-mechanical characteristics of soil on the testing site

Parameters		EGL, (thickness, m)			
		3, (3.1-3.3)	4, (2.0-2.6)	5, (2.6-3.2)	6, (2.8-3.0)
Water content *W*, %		21.8	24.2	24.9	22.5
Plasticity index I_P, arb.un		-	9	14	-
Natural bulk density *ρ*, g/cm^3		1.97	1.76	1.84	2.01
Void ratio *e*, arb.un.		0.642	0.887	0.818	0.63
Friction angle, degrees	φ	32	14	15	32
Cohesion, kPa	C	2	12	16	2
Secant stiffness modulus, MPa	E	29	6	7.2	30

The testing site was separated from the pile foundation to conduct the test (marked in red in Fig. 1).

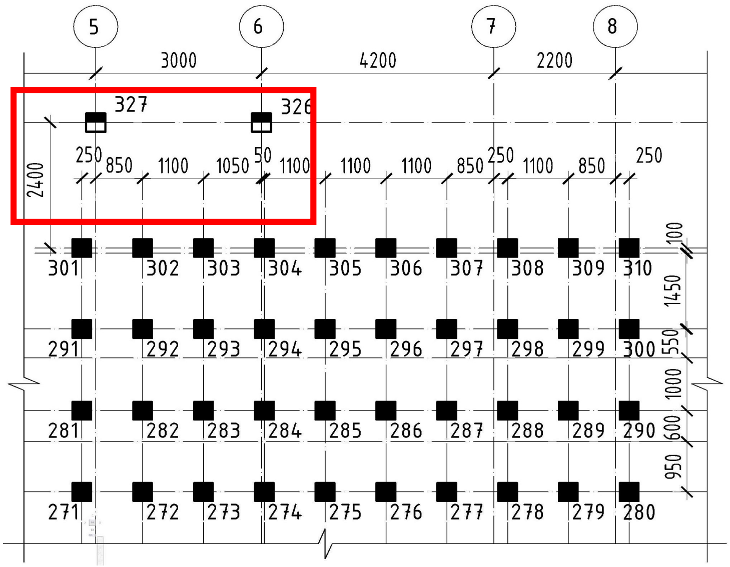


Fig. 1. Layout of the pile foundation (the tested zone is indicated by red color)

The tested zone (Fig. 2) included the test pile (No. 327) and the additional adjacent pile (No. 326).

All the piles are manufactured reinforced concrete piles with the cross-section of 350×350 mm. The piles were driven into soil to the 8.5-m depth. The piles were installed within four layers (EGLs). The bottom of the piles where located in the EGL 6.

The distance between piles Nos. 327 and 326 was 3 m (the width of the side of the pile multiplied by 7). The distance from the test pile to adjacent pile No. 301 was 2.4 m (Fig. 2). A cast-in-place reinforced concrete plate unconnected to a pile was constructed around the tested pile. The presented test conditions responded to the full-scale conditions of pile foundation.

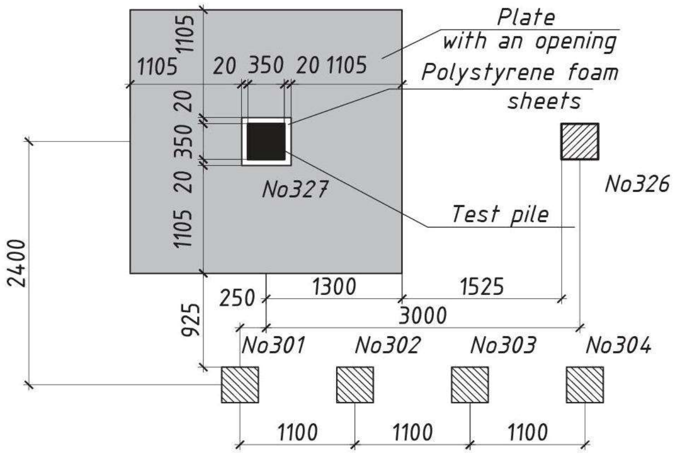
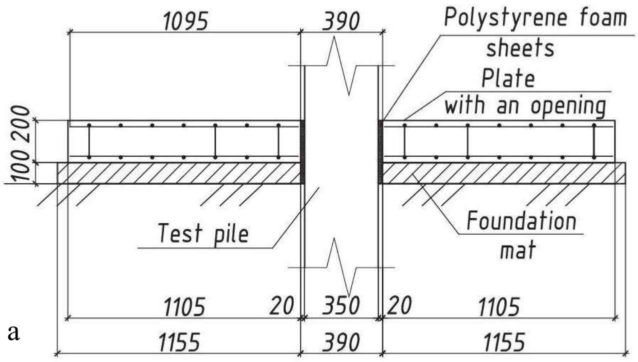


Fig 2. The layout of piles in the tested zone and the raft opening around the tested pile

The dimensions of the reinforced concrete plate were 2600×2600 mm, the thickness is 200 mm. The raft is made of C20/25 concrete. Moreover, a lean concrete foundation mat made of 100-mm C8/10 concrete was used and installed under the raft (Fig. 3a). The reinforcement of the raft consisted of 10-mm bars with 150-mm space interval (Fig. 3).

To separate the raft from the tested pile, at the stage of concreting, 20-mm foam polystyrene sheets were used (Fig. 3b).



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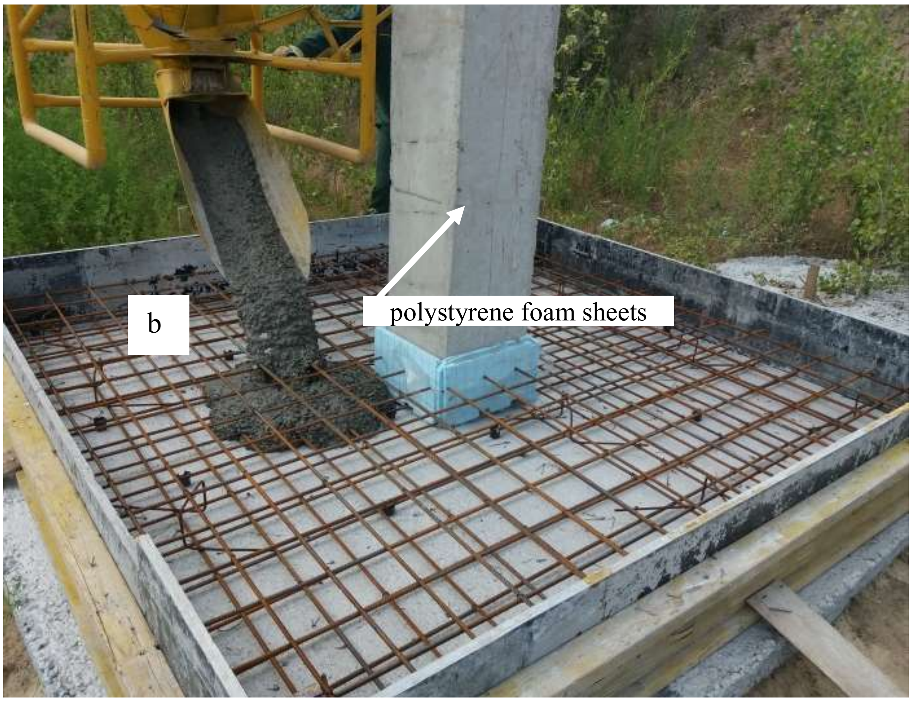

Fig. 3. Details of the raft and the pile: a) a cross-section of the raft, b) the process of concrete casting around a pile

3. STAGES OF THE FULL-SCALE FIELD TEST

The method of field tests consists in the observation of displacements (settlements) of the tested pile unconnected to the raft and adjacent piles under the static loading of the raft.

The raft was loaded with reinforced concrete slabs (64.2 t) (Figs. 4 and 5b). They were installed with the help of a cargo self-propelled crane. The raft was loaded in three increments: 292.4 kN, 180 kN, and 170 kN.

To observe the pile displacement, optical levelling (Ni 007, Carl Zeiss, Germany) was used to monitor the settlements of the piles and the raft (Fig. 4).

The average measurement error for 1 km of a double line is ± 0.5 mm (with the use of a micrometer) and ±2.0 mm (without a micrometer). The optical leveller was placed by 14.5 m away from pile No. 327 (Fig. 4).

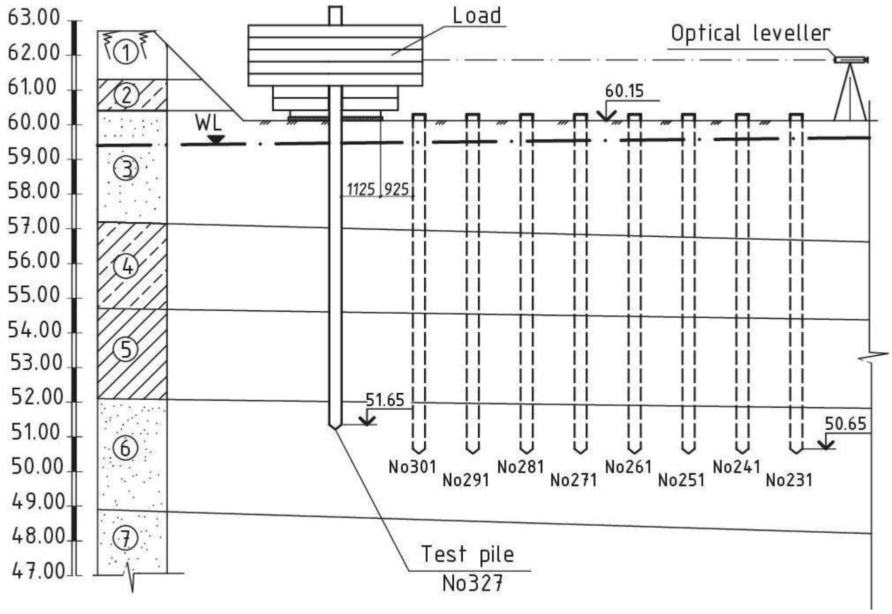

Fig. 4. The layout of tested pile No. 327 (unconnected with the raft) loaded up to 642.4 kN

Procedures of a full-scale field test included:

1) installation of a 100-mm concrete foundation mat around the tested pile (they are not connected) (Fig. 3a);
2) installation of a 200-mm raft around the tested pile (they are not connected) (Figs. 3b and 5a);
3) recording of displacements of the pile and the raft with an opening with the use of a leveller (Fig. 4);
4) application of a load equal to 292.4 kN to the raft (Fig. 4);
5) recording of the displacements of the piles and the raft, application of a load equal to 292.4 kN (interval between the increments of load application is 2 weeks, the total load is as high as 642.4 kN) (Fig. 5b);
6) recording of displacements of the raft and the piles weekly during a month with the help of a leveller;
7) unloading the raft and the recording of the displacements of the raft and the piles.

The maximum load on the raft was chosen by the criterion of maximum pressure under the raft not exceeding 100 kN/m^2. With regard to the weight of the raft and the loads, the total load applied to the soil under the raft was 97.2 kN/m^2.

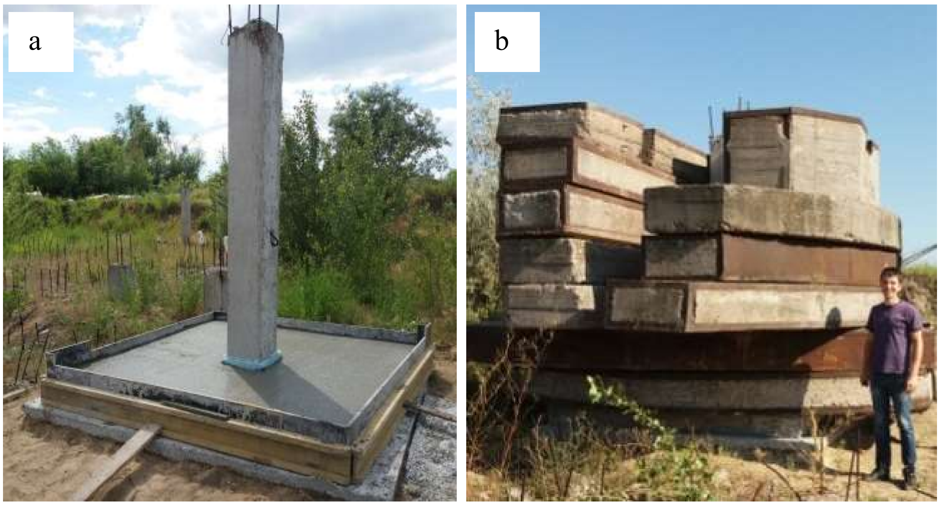

Fig. 5. Pile foundation fragment a) reinforced plate with an opening and the pile;
b) application of the maximum load

The results of monthly observations of displacements of the piles and the raft are presented in Table 2.

Table 2. Displacements (settlement) of the plate and the experimental piles

	Settlement / Load, kPa	Full-scale test		
		S_{plate}, mm	$S_{test\ pile\ 327}$, mm	$S_{pile\ 326}$, mm
Raft loading	44.2	6.56	0.7	0.11
	71.4	10.6	1.51	0.61
	97.2	14.6	2.48	0.92
Raft unloading	71.4	14.2	2.35	0.98
	44.2	13.7	2.27	0.88
	0	13.2	2.17	0.8
Unloaded state for 28 days	-	8.5	1.5	0.5

Based on the results of observations, plots presenting the dependence of the settlement of the raft, tested pile, and adjacent piles on the load of the raft S=f(P) have been prepared. As seen in Fig. 6, the maximum load resulted in 14.6 mm displacement of the raft (curve 1). Soil displacement caused negative skin friction forces acting along the test pile (No. 327), and thus its displacement by 2.48 mm (curve 2 in Fig. 6).

The adjacent pile No. 326 placed 3 m away from the tested pile settled by 0.92 mm (curve 3 in Fig. 6).

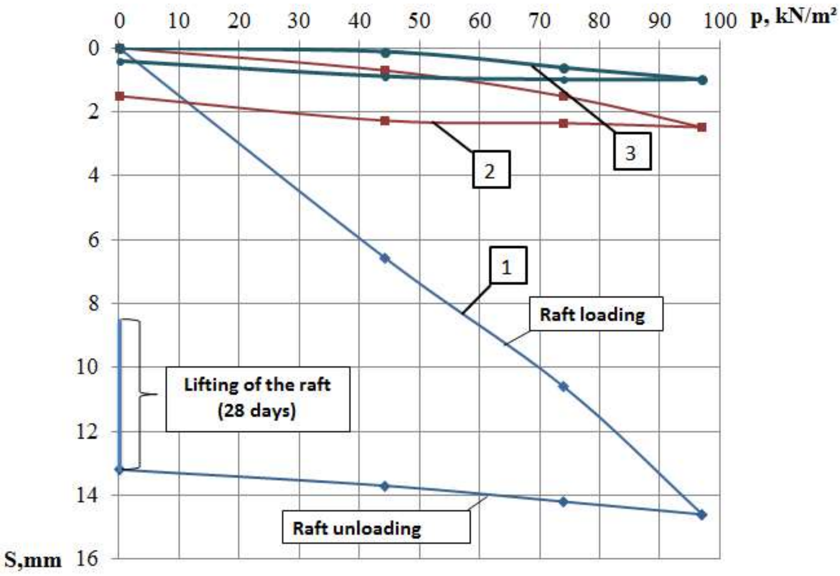

Fig. 6. Plots: “loading – settlement” of piles and the raft: 1 – settlement of the raft; 2 – settlement of pile No. 327; 3 – settlement of pile No. 326

After the unloading, the raft and the pile, due to the elastic behavior of soil, lifted by 1.4 mm and 0.3 mm, respectively, relative to their positions under the maximum loading.

In 28 days, the raft and the pile lifted by additional 6.1 mm and 1 mm, respectively (Table 2, Fig. 6).

4. CONCLUSIONS

1. New experimental “load-settlement” dependences for a pile foundation fragment under field conditions have been obtained. The loading was applied to the raft which was not connected to a pile. Thus, the influence of the pile displacements on the raft settlement have been determined.
2. Settlement of the tested pile No. 327 and the adjacent pile №326 was caused by negative skin friction forces resulting from the raft loading. The experiments showed that it is possible to monitor such displacements and control them in field tests.
3. The maximum settlement of pile No. 327 was 17.8 % of the total raft settlement. The settlement of adjacent pile No. 326 installed 3 m away from the tested one is 6.3 % of the total settlement of the raft.

4. The results of this field test can be used to compare and assess the results and validity of the subsequent numerical modelling of the incremental loading of components of the pile foundation, which are not connected one with another.

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