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Model tests of piled raft foundation

Essais en modèle réduit de la plaque de fondation sur pieux

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ABSTRACT
The problem of contribution of piles and slab in transmission of load into the subsoil by piled raft foundation is discussed. In the paper the results of model tests aiming at the analysis of the problem for various number of piles and its spacing are presented. Piles-slab-subsoil interaction is determined by the effectiveness coefficient η.

RÉSUMÉ
La répartition de la charge entre les pieux et la plaque de foundation est un des problèmes foundamentaux de l'analyse de foundation sur pieux. Nous avons presenté ici les résultats des essais en modèle réduit avec le nombre et la répartition des pieux differents. Les effets de l'interaction des pieux, de la plaque de foundation et du sol sont determinés par le coefficient η.

1 INTRODUCTION

Recently, in geotechnical practice more commonly are applied piled raft foundations, which transmit the loads into the subsoil by piles as well as a slab. Proper determination of the contribution of piles and slab in load transmission is one of the basic problems characterizing the work of such foundations, Chow (1986), Gwizdala and Dyka (2002), Tejchman et al. (2002).

The issue is still the subject of research work including model and field tests as well as theoretical studies.

In the paper the results of model tests regarding interaction between piles, slab and subsoil for various numbers of piles and its spacing are presented.

2 SMALL SCALE MODEL TESTS

Although the model tests can not replace in situ measurements and investigations, nevertheless they are very useful in better understanding the problem of interaction between the foundation and the subsoil and particularly can serve for observations of the phenomena which occur during such tests, especially at ultimate loads. Therefore, model tests are very important and sometimes they are the only possibility for solving complex engineering problems and recognition of governing mechanisms.

The model tests described below have been carried out in the Geotechnical Department Laboratory at Gdansk Technical University. In the tests 1:20 model of steel slab foundation on piles was used, Slabek (2003). Testing program was oriented at an analysis of slab-pile-subsoil interaction and specifically at the determination of contribution of a slab and piles in transmission of vertical loads. It covered the model tests with the slab without piles, group of piles with various spacing and finally with the slab on piles with assured contact between slab and subsoil.

2.1 *Soil medium*

All model tests were performed using uniform, fine quartz sand with unit weight of soil particles γ_s = 26 kN/m^3 and dry unit weight γ_d = 15,6 kN/m^3. Other soil parameters are shown in the table below:

Tabele 1: Soil parameters

moisture content (average)	w_{aver}	3.5	[%]
angle of internal friction	ϕ	30°	[°]
min. density of dry soil	ρ_{dmin}	1.49	[t/m^3]
max. density of dry soil	ρ_{dmax}	1.77	[t/m^3]
density index	I_D	0.25÷0.28	[–]
coefficient of uniformity $C_U = d_{60}/d_{10}$	C_U	1.39	[–]
median grain size	d_{50}	0.21	[mm]

2.2 *Lab stand*

The tests have been carried out in a stand for model tests in wet non-cohesive soil medium. Scheme of lab stand is presented in Fig. 1.

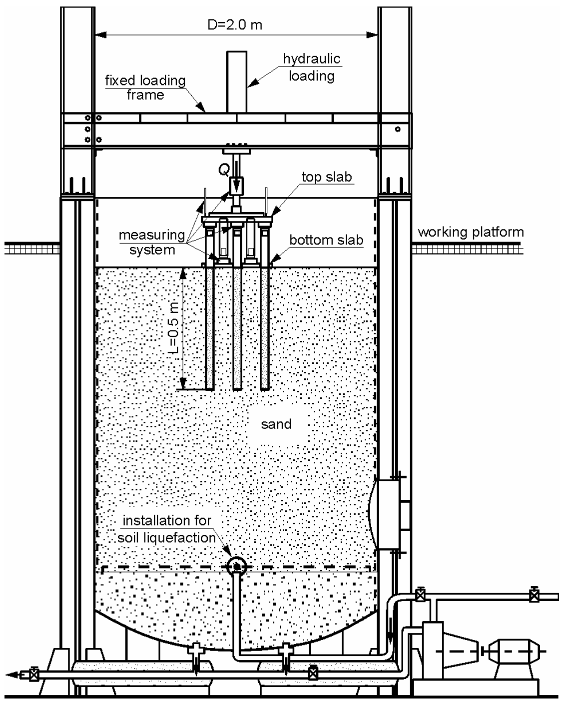

Figure 1 Scheme of lab stand for wet non-cohesive soil.

2.3 *Piled raft foundation model*

In all tests one model of slab foundations of the dimensions 30 x 30 cm was used. It enabled testing pile-slab-subsoil interaction for six sets of piles working as a group. The model construction which was shown in Fig. 2 consists of three main parts, namely: group of piles, bottom and top slabs. The latter were equipped in tensometer load gauges for measurement the loads transmitted onto individual piles and the slab.
Model piles were made of steel tubes of the diameter of 32 mm and the in-soil length of 0.50 m, with standard shaft roughness achieved by gluing it with the model sand.

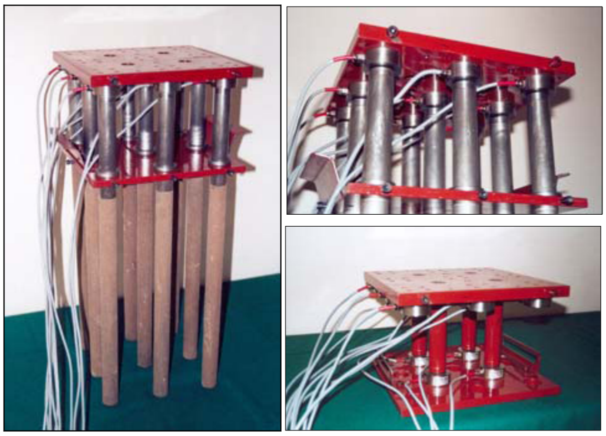

Figure 2 Piled raft foundation model.

3 TESTING PROGRAM AND PREPARATION PROCEDURE

Preparation of the subsoil in the tank as well as installation of the pile model was made by liquefaction of the soil. Due to forced, upward water flow the subsoil liquefied becoming dense suspension, easy to be mixed. The mixing lasted until the sedimentation process started. Such a procedure assured uniform subsoil's density, the density index of which was varying from $I_D = 0.25$ to 0.28 in the whole mass of the soil. During this stage the pile model was embedded into the soil, however suspended to the loading frame. After sedimentation process the model which was first connected to the loading device and measuring system, was then pushed into the subsoil with constant rate of 2 mm/min. During pushing, magnitudes of total load acting on the pile model, displacements as well as individual load contributions of loads acting on piles and slab independently, were recorded.

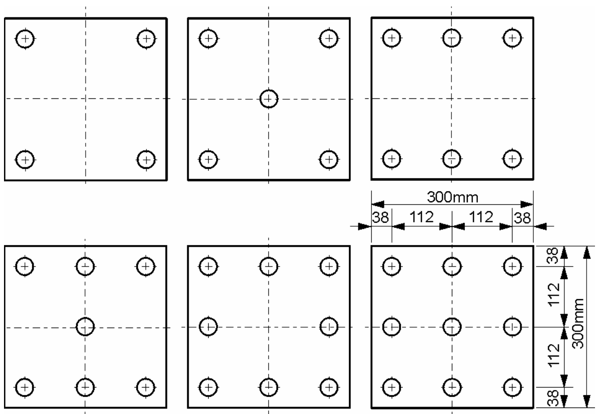

Figure 3 Schemes of various sets of pile groups and piled raft foundations.

The following four basic tests have been carried out:
a) model tests on the foundation slab – P1
b) model tests on the single pile – 1p,
c) model test on the group of piles – 4p, 5p, 6p, 7p, 8p, 9p,
d) model tests of the piled raft foundation (group of piles capped by the slab) – R1, R4, R5, R6, R7, R8, R9.

Model tests of the group of piles and piled raft foundations have been carried out for six different pile sets, in which the groups consisting of 4 and 9 piles were investigated, see Fig. 3. Totally 48 experiments were made in 2 or 3 series for each individual test representing different set of piles.

4 TEST RESULTS

Loading test results obtained from each experiment were the basis for determination of load-settlement curves. All curves had the same shape close to parabola. The relations between loads and settlements for groups of piles and piled raft foundations are collated in Figs. 4 and 5, respectively.

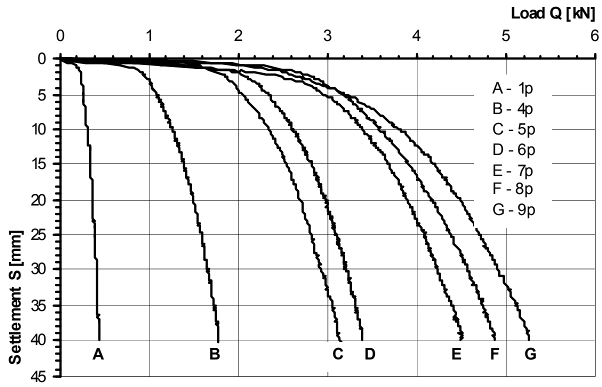

Figure 4 Load-settlement relations for groups of piles.

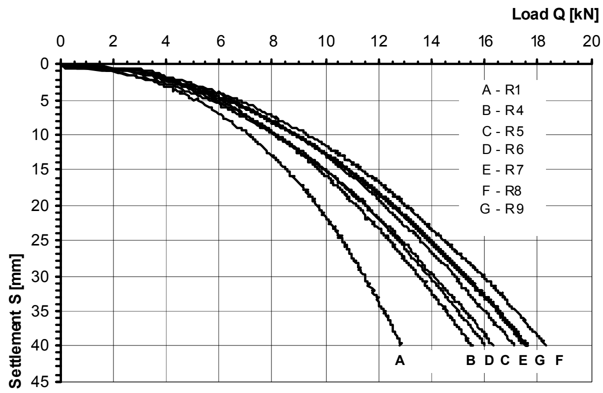

Figure 5 The comparison between averaged load-settlement relations.

The results obtained served for comparative analysis of the loads acting on the slab, group of piles and piled raft foundations. The basis of such analysis were the results of tests made on single pile and slab founded directly on the ground, which were the reference level for the results of pile group and piled raft foundation model tests for various number of piles and its spacing. Chosen results of such comparison for 7 piles' scheme (7p), in the form of load-settlement curves are shown in Fig. 6.

The main goal of the experimental studies, described on the basis of example shown above, was a determination of the piles and slab contribution in transmission of loads into the subsoil.

An example of the division of loads for 7 piles' scheme was shown in Fig. 7. Applied methodology enabled direct assessment of percentage contribution of piles and slab in transmission of loads into the subsoil for the remaining 6 testing schemes.

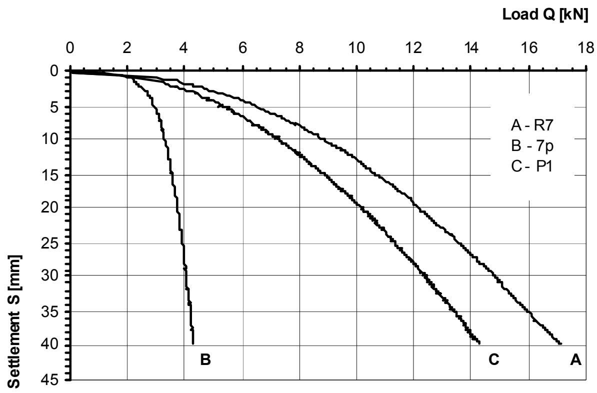

Figure 6 Load-settlements curves for 7 piles' scheme.

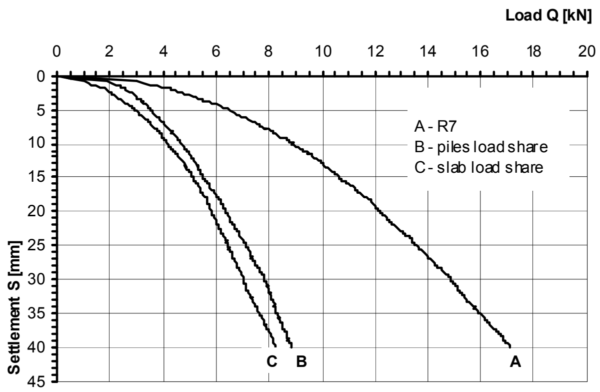

Figure 7 Contribution of slab and piles in transmission of loads into the subsoil. Slab on 7 piles.

The results obtained show that an increase of piles number under the slab caused an increase piles' contribution at the cost of slab which was restricting its interaction with the subsoil to the external area outside the group of piles. It should be also noted the increase of piles number caused the decrease of rate of total bearing capacity of the foundation.

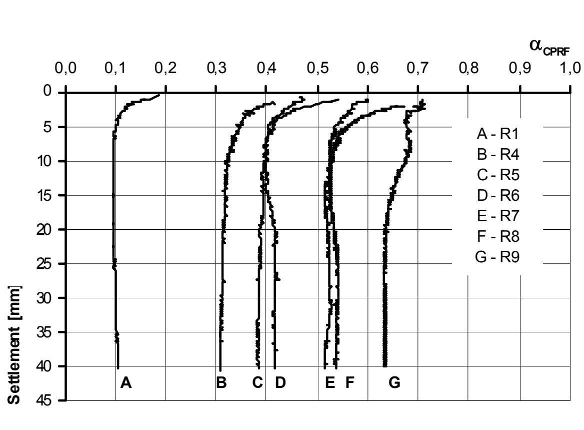

Figure 8 α_{CPRF} ratio determined by model tests.

In general, the contribution of piles and slab in piled raft foundation is usually described by α_{CPRF} which is defined as a ratio of load transmitted by all piles in foundation and total load acting on it:

$$\alpha_{CPRF} = \frac{R_{pile}}{R_{total}} \tag{1}$$

For pure schemes of shallow and pile foundations the ratio is $\alpha_{CPRF} = 0$ and 1, respectively. In Fig. 8 the contribution of loads for all 7 testing schemes studied here are presented. It may be seen that for single pile the ratio is close to 0 whereas for 9 piles is equal to 0.65-0.70 Similar studies were made in Darmstand under supervision of prof. Katzenbach; see Turek and Katzenbach, (2003).

In order to describe the work of piled raft foundation with respect to corresponding pile group or a slab founded directly on the ground the effectiveness coefficient η of piled raft foundation was introduced. It describes the ratio of the bearing capacity of piled raft foundation to the sum of respective bearing capacities of shallow slab foundation and group of piles. The role of the effectiveness coefficient was to confirm whether the load transmitted into the subsoil by piled raft foundation model is higher than the algebraic sum of loads transmitted by the group of piles and shallow foundation.

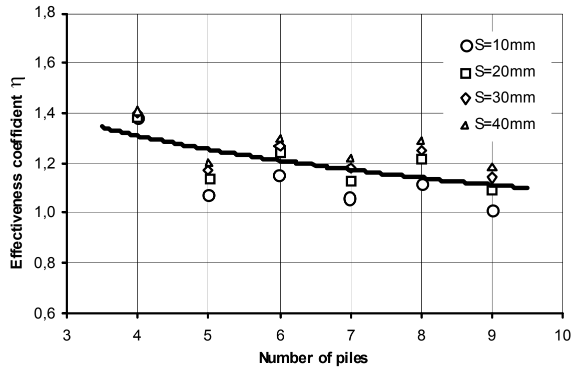

Figure 9 Effectiveness coefficient η of piled raft foundation

Such comparison has been shown in Fig. 9. It can be seen that, the effectiveness coefficient is higher than 1.0 what shows that pile-slab interaction contributes to the increase of the bearing capacity of the foundation. The maximum effectiveness (η = 1.4) was reached for raft foundation with four piles, for whole settlement range whereas for 9 piles the corresponding coefficient was equal to 1.1, only. It confirms former conclusion regarding the ultimate number of piles above which the increase of bearing capacity is not observed.

5 CALCULATIONS OF REAL FOUNDATION

The analysis of the results of model tests regarding the interaction between slab, piles and subsoil together with conclusions drawn were used in the design calculations of foundations for tanks of primary sewage-treatment plant in Tychy Brewery, Poland. Five tanks were designed to be founded on piled raft foundation taking into account the subsoil-foundation interaction. Original design approach considered foundation onto the group of piles, only. Calculations which concerned the contribution of slab in transmission of loads let to shorten the length of piles of 3.0 m, on average, see Tejchman et al. (2004).

6 SUMMARY

The model tests performed allowed for the determination of the piles and slab contribution in transmission of loads into the uniform subsoil for different number of piles and its sets. Observed contribution of the slab was varying from 60% to 70% for three sets of piles (Nos. R4, R5 and R6) and was decreasing with increasing number of piles. For the number of piles over six, higher percentage of load was transmitted by piles (from 50% to 56%). The model tests were carried out in loose subsoil (I_D = 0.25÷0.28), built of fine sand.

Based on the slab effectiveness coefficient it was found that bearing capacity of piled raft foundation is higher than the algebraic sum of the slab and group of piles working independently. Maximum increase of bearing capacity, up to 40% was observed for raft foundation with four piles. It is planned to use the results obtained for the numerical analysis of the problem of subsoil-raft foundation interaction.

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