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PROBLEMS IN RECONSTRUCTION OF PILE-RAFT FOUNDATION

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In practice, in many cases using combination of piles and large-slabs could be observed technological and structural defects before the start of their operation. These defects are dictated by the complex interaction between piles system and thin raft slabs. In order to establish the causes of defects can be imposed a wide range of studies covering research on the ground, the reinforced concrete structural elements and materials (piles and raft), the technology performance and others. In this study in order to identify the causes of defects are used a series of research methods for determining the properties of materials, environmental conditions and computational models to describe the interaction between ground and upper structure. With this set of methods are established causes and selected measures for appropriate reconstruction. The scope of these measures consists in the use of a combination of hardening by injection of the ground under the contact base of raft. With grouting the aims are to improve the skin friction and end bearing resistance of the piles. In the complex decision are sought the approaches to keep the completed structures - piles and raft. The focus of this work is to improve the interaction of the pile-raft system and ground base at the expense of reducing the load on piles. In this case, the geological formation, represented by Paleogene sediments with alternating layers of hard clay and clay sandstones largely supports the realization of the design measures.

Keywords: Renovation, Defects, Soil structure interaction, Grouting.

1 INTRODUCTION

Usually, in such cases the investigation of the problems starts with the analysis of the causes of the defects detected by visual and instrumentation devices. Due to the huge of engineering technologies such investigations are possible, but in most common cases the selection of the tools and procedure consequence depends on the financial and technical restrictions. In general, the examination of such complex situations, involved in the scope of soil structure interaction, requires research of the following:

- Ground, geological formation and its modifications in the building process;
- Climatic conditions during the implementation of pilot works and reinforced concrete structures;
- Quality of materials;
- Media conditions and measures for early stage of concrete curing.

The conventional approaches for increasing of the bearing capacity of the elements with good economic results have been prioritized, but they have to be examined in view of the general context of the issue.

The investigation of the complex of soil structure interactions could use the defects and damages reliably as a tool for verification of the analytical models. In the present task this feature is applied both for the formulation of suitable models that use the defects and as an indicator for development of some processes. These processes are described and examined by the means of different calculation procedures.

2 DESCRIPTION OF THE STRUCTURE SOLUTION

The structure made by the beginning of the present researches is a pile-raft system. The total area of the foundation is 2400 m^2 of round shape layout. The manufactured piles are of 0.9 m diameter of 10 m length, located in a regular grade of 4 m step. Reinforced slab of 0.6 m thickness is made on the pile. The slab has fixed thickness on the whole foundation area and it is placed on the compacted embankment of crushed rock of 0.3 m thickness.

For the execution of the different structure elements of the foundation, some conventional technologies are used. The piles are drilled and poured by the means of casing and drilling by Kelly bar without any protection against the bentonite suspension. The placement of the reinforcement is made before the concreting and the concrete is placed using the contraction technology.

The slab is manufactured according to the classical technology and the concrete is placed in a scheme with consequent zigzag movements of the concrete placer.

3 DESCRIPTION OF THE DETECTED DEFECTS IN THE STRUCTURE

One week after the concrete placement for the pile-raft some cracks in radial and ring directions have been detected in it. Based on the following researches made by drilling it is established that the cracks pass through the whole slab cross-section. Later these cracks expand up to 1-2 mm.

There is another main defect detected during the manufacturing of the piles. For the cases of piles of such relatively big diameter, the problem related to the provision of good back resistance is well known. By drilling of the piles throughout the cross-section of the reinforcement next to the bottom some caverns have been detected. These features assume relatively big initial settlements of the piles and sliding in the contact area of the pile and soil.

All these features mostly outline the directions of the needed researches, the comprehensive extent and the methods applicable for structure analysis.

3.1 Conducted Researches

The elaborated research program includes in situ CPTU and DPSH soil researches. All geological data currently collected from the drilling and laboratory teste are summarized. Some piles are drilled alongside their entire length and in the area under the bottom. The manner and type of the reinforcement of the pile-raft are determined by non-destructive methods and removal of the concrete covering. In order to

determine the compressive strength of the concrete some samples from the concrete are provided.

Data based on the climatic monitoring of the region during concreting of slab until the moment of conducting of the researches are generalized.

High-accuracy geodetic measurements are made of the upper surface of the slab. These measurements were compared with the design assumptions and some displacements of the structure have been detected. Based on the collected number of data series of numerical analyses have been conducted, in order to track the processes that have been developed in the structure and caused the defects.

3.2 Geotechnical Researches

Geotechnical researches conducted within the framework of the whole research aim to verify the plausibility of the data from the previous geological investigations, which are performed during the design stage.

By the performed CPTU and DPSH, made from the level of the formed soil surface, a data set has been collected and used for the analyses. It has been compared with the laboratory data.

Table 1. Laboratory data.

		Specific density	**Void ratio**	**Natural water content**	**Max water content**	**Dry density**	**Natural density**	**Plastic index**	**Compression parameters**	**Characteristics of the peak shear strength**	
		ρ_s	e	w_n	w_r	ρ_d	ρ_n	I_p	C_c	c'	φ'
		g/cm^3		%	%	g/cm^3	g/cm^3			kPa	deg
Layer 3 - Powdered clay											
Average value	X_{avg}	2,69	0.66	18.76	25.09	1.63	1.92	13,26	0,074	23	23
LCV *		2.53	0.27	9.71	11.11	1.28	1.66		0.060	19	19
UCV**		2.85	1.05	27.81	39.06	1.97	2.18		0.089	28	28
Layer 4 - Soft clayey sandstone											
Average value	X_{avg}	2.66	0.87	29.11	32.66	1.43	1.84	25.79	0.104	60	19
LCV		2.52	0.59	18.27	22.97	1.24	1.71		0.052	31	11
UCV		2.79	1.15	39.95	42.35	1.62	1.96		0.155	88	27
Layer 5 - Powdered clay											
Average value	X_{avg}	2.67	0.77	22.86	28.79	1.52	1.85	13.87	0.078	30	25
LCV		2.58	0.50	14.86	19.08	1.30	1.61		0.029	24	20
UCV		2.75	1.04	30.86	38.50	1.73	2.09		0.127	35	30
Layer 6 - Clayey sandstone											
Average value	X_{avg}	2.71	0.75	25.23	27.76	1.55	1.90	22.90	0.067	52	21
LCV		2.47	0.56	18.59	20.45	1.14	1.40		0.049	39	15
UCV		2.94	0.95	31.87	35.06	1.95	2.40		0.085	66	26

**LCV - Low characteristic value, **UCV - Upper characteristic value*

The in situ investigations confirmed the stratigraphic features of the massif, but also some considerable differences between the physical and mechanical properties of

the soil varieties have been detected. For comparison of the data in Tables 1 and 2 the results of the laboratory and field tests of the area are provided.

The processing of the single results is made pursuant to EN 1990. The use of this approach allows exclusion and adding of new tests to the number of results in order to achieve plausibility.

General information about the location of the stratigraphic units with a typical geological section is provided. It shows typical structure of the Paleogene sediments in the region.

Table 2. Correlated data from DPSH.

DPSH	Nspt	Terzaghi-Peck		Terzaghi-Peck (1967)	Mayne, 1998 Kulhawy and Mayne, 1990	Wolff, 1989	Bowles 1996	D'Appolonia *et al*. 1970	Michell & Gardner (1975)	Callanan & Kulhawy (1985)
		$I_{c,min}$	$I_{c,max}$	c_u	φ	φ	Young's mololus E_b			
N	pcs			kPa	deg	deg	kPa			
Layer 3 - Silty clay										
Average value	20-28	0.58	0.83	181	40	35	21566	39099	28132	42198
LCV		0.46	0.67	146	33	28	17420	31582	22723	34085
UCV		0.69	0.98	216	48	42	25712	46616	33540	50310
Layer 4 - Soft clayey sandstone										
Average value	22-36	0.60	0.85	172	41	36	20888	42150	26776	40165
LCV		0.36	0.61	139	30	26	16872	10039	21628	32443
UCV		0.84	1.09	205	53	46	24904	74260	31925	47887
Layer 5 - Silty clay										
Average value	35-50	0.75	1.00	327	48	41	32545	55568	50091	75136
LCV		0.55	0.74	241	35	30	23982	40947	36911	55367
UCV		0.95	1.26	414	60	51	41109	70189	63271	94906

3.3 Investigation of the Concrete Properties

Based on the research program a task for investigation of the mechanical concrete properties in the reinforced structures is established. The research procedure is conducted by the means of cylindrical sampling bodies of 150 mm (standard for such type of concrete). Lower indicators of the pressure strength have been established.

3.4 Calculation Analysis

The calculation analyses in this design situation are mostly used for identification of the causes of the defects occurred in the structure. The analyses have been made using two software products – Plaxis and SAP. Plaxis software is used for preliminary investigation and determination of the parameters of the soil structure interconnection. Thus, the Winckler parameters (coefficient of subgrade reaction) for all three spatial directions are determined. The used models are shown on Figure 1 & 2.

Based on the parameters of the soil structure interconnection a spatial model is established, which is investigated in elastic and elastic-plastic behavior of the materials.

The researches cover the loading conditions before the beginning of the operation of the facility and they include thermodynamic analysis of the concrete exothermity and registered loading conditions in the building process.

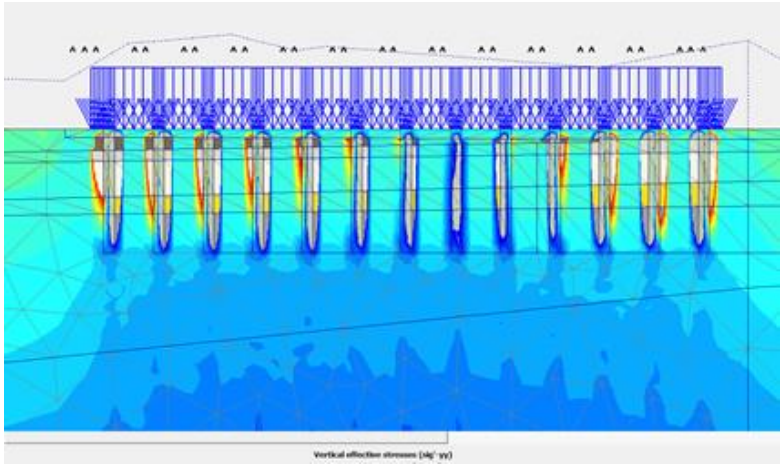
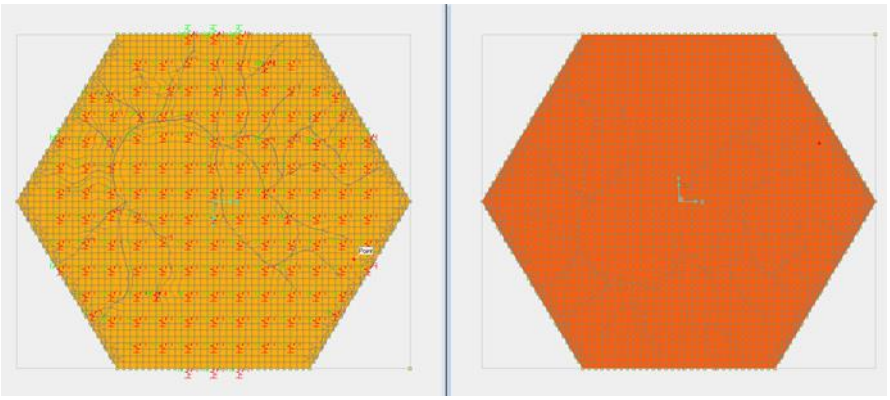


Figure 1. 2D model for research of the interconnection of the pile-slab system.



Upper surface Lower surface

Figure 2. 3D model of the upper pile slab with registered cracks.

The results of this model research are used for verification of the reinforced cross-sections for states of opening and development of cracks with material characteristics in early concrete age.

4 CONCLUSIONS

The main objective of this study is to select measures and to undertake solutions able to restore the design operation suitability and long life of the facility. The main

conclusions made by the research, based on the implemented structure and model analyses, allow describing of the following main conclusions:

- For such kind of problems, it is important to formulate the calculation models, which describe reliably the limit states both during the construction process and during the operation. Due to the complicated nature of the structure operation, it would be difficult to implement this only by one calculation model. The complicated scheme of soil structure interaction imposes a risk of use of too complicated models that could not be verified.
- The use of large diameter piles and thin slab with big dimensions establish conditions for restriction of the temperature deformations. The soil properties and the piles rigidity should be considered. The selection of the design concept should pass series of preliminary analyses for selection of pile diameters.
- Special attention should be paid on the structure of the reinforcement in the slab. This reinforcement should be determined based on an analysis of the Serviceability Limit State (SLS) - opening and expanding of cracks in early stage of the concrete strength. The detected stress-strain conditions in the slab show development of big normal forces, which are the most probable cause for the cracking systems detected by the measurements.

Based on these conclusions in the concrete situation, some reconstruction measures are offered, including the following solutions:

Injection of clayey-silica content to an area under the pile-raft slab. The scope of the injection is determined by settlement analysis. Thus, the soil slab interaction as well as the allocation of the forces in the system is improved. The results of the model analyses with this intervention show equal allocation of the internal forces and settlements. The injected compound has been studied in a tested section and after the injection in this area an in situ test was made (DPSH). The results of the in situ tests show increasing of the mechanical parameters of the area after the intervention into the massif. The use of the injection compounds has been made with control of the pressures, maintained in order to prevent deteriorations of the soil natural structure.

Based on the solution a general conclusion might be drawn that the success of the work in such solutions could be achieved in conditions where the slab interaction forces are comparable with the forces determined for the piles. In such solutions the forces are optimally allocated and they do not give any hint about the development of the deformations causing disturbances of the operation conditions.

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