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TC 18 Activity Report – Summary

Résumé du compte rendu d'activité de la CT N° 18

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INTRODUCTION

The ITC-18 as a group was focussing over the past four years on some of the terms of reference as stipulated below :

- To undertake a synthesis of the design criteria for pile foundations referring both to the ultimate and to the serviceability limit states with special emphasis on the pile foundations for which the applied load is shared partially by piles and partially by the foundation raft ;
- To establish terms of reference for the installation, design and performance of different type of auger piles ;
- To explore the possibility of interaction and co-operation with the Deep Foundation Institute ;
- To organize a Special Conference devoted to the themes pertinent to the work of TC-18.

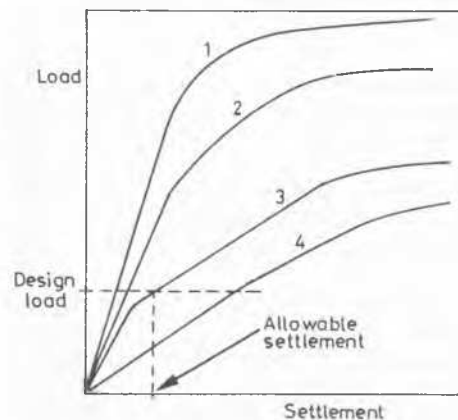
The work resulted in the final full report on piled rafts, available to the ISSMFE-members on request. Moreover, a workshop in Ghent (April 1997) and during the Hamburg Conference (September 1997) reinforced the exchange of ideas mainly related to pile raft topic. As a second part of the TC-18 work, the draft on auger pile behaviour was prepared.

PART I : PILED RAFTS

For every pile group foundation requires a cap in order to allow the piles acting as a group, the key question is whether the pile cap can be taken into account in the foundation design increasing the overall foundation stiffness rather than only act as an additional load (fig.1).

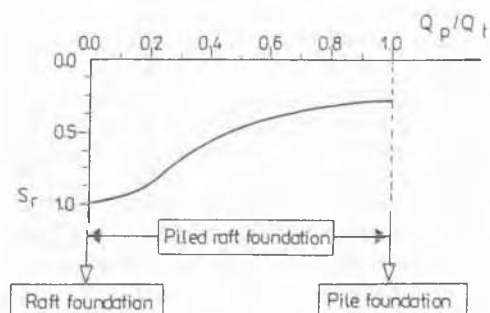
Depending on the working principle implemented in the deep foundation design, one of the following three cases will be the closest to real piled raft behaviour :

- the piles are supposed to carry the full load ; the raft does not contribute



- Curve 1 : raft with piles designed for conventional safety factor
- Curve 2 : raft with piles designed for much lower safety factor
- Curve 3 : raft with piles designed at full capacity
- Curve 4 : raft only (excessive settlement)

Figure 1. Alternative design strategies for piled rafts



- Q_p - pile load ; Q_t - total load ; S_r - settlement reduction

Figure 2. The efficiency of piles as settlement reducers in a piled raft foundation

- b. the piles act as partially settlement reducers for the raft remaining still the less important bearing element of the foundation system
- c. the piles are provided as full settlement reducers operating at a shaft factor of $F_s = 1$. The raft becomes the principal bearing element of the foundation.

Fig. 2 demonstrates just qualitatively, the decay curve of the settlement reduction of a piled raft foundation in comparison with the corresponding unpiled raft foundation.

$$S_r = \frac{\text{settlement of piled raft foundation}}{\text{settlement of corresponding unpiled raft}}$$

In reviewing the more significant developments in the area of soil-foundation interaction related to the piled raft foundations, the attention can initially be restricted to settlement prediction methods of vertical pile groups subjected to axial loading.

A sound prediction of a piled raft behaviour implies a full interaction between piles, raft, and soil ; hence the influencing factors to be considered are :

- i. the raft characteristics (the relative stiffness, shape)
- ii. the characteristics of the piles (the number, layout, length, diameter, and stiffness of the piles)
- iii. the characteristics of the applied load (concentrated or distributed loading, and its level relative to the ultimate capacity)
- iv. the characteristics of the soil (the soil profile, the various layers, their stiffnesses, the ultimate unit soil bearing capacity beneath the raft). Common methods for settlement prediction of piled rafts are presented and a classification is shown in table 1.

In 1991, Poulos suggested, based on case studies, that the following situations are the most favorable ones for piled rafts :

- a. a soil profile consisting of a uniform layer of relatively stiff clay
- b. a uniform soil profile consisting of relatively dense sands
- c. a layered soil profile in which beneath the likely foundation depth of the piles, all bearing layers are very dense or stiff.

Consequently, the following situations are the most unfavorable cases for applying a piled raft :

- a) a soil profile consisting of relatively soft clays near the natural ground level
- b) a soil profile consisting of relatively loose sands near the natural ground level
- c) soil profiles from the foundation level of the piles on, which are still consolidating underneath the pile group foundation level.

Poulos stated in his Rankine Lecture (1989) that the effect on pile group settlement of the pile cap in contact with the soil underneath is relatively small unless the pile spacing is large and the group remains relatively small. It has been shown that for piles at a center-to-center distance of 10 diameters, the reduction in settlement due to cap contact is only about 5% ; for such purposes and at working load, the beneficial influence of the cap-pile interaction can be ignored. On the contrary (Van Impe 1991) for more practical cases of smaller interdistance (3 ϕ -4 ϕ pile), the effect of the pile cap-pile group interaction on the overall load-settlement behaviour can not be neglected ; in many of such pile groups (of the displacement pile type) more than 25% of the load can be taken by the flexible raft-soil interaction directly.

A survey of the published relevant papers on the piled raft topic has been elaborated in a comprehensive document of the

Table 1. Methods of settlement prediction for piled rafts

Categories	Authors	Main approach	Type of interaction in the analytical model
Simplified methods	Randolph (1996)	A single pile-cap unit applied to the equivalent pier approach	pile-cap and pile-soil (pile considered as equivalent pier) interactions
	Randolph and Clancy (1993)	Piled raft divided in single pile-cap units	pile group-cap and pile group-soil interactions
	Tomono and Yamashita (1987)	Finite element approach coupled with interaction factors using Mindlin's solution	pile-pile, pile-soil surface, soil surface-pile, and surface pressure-soil surface interactions
	Van Impe and De Clercq (1994)	Piled-raft units coupled by elastic interaction solutions	pile base-pile base, pile shaft-pile shaft, pile base-pile cap, pile shaft-pile cap, cap-pilebase, and cap-pile shaft interactions
	Poulos (1994)	Finite difference approach with piles assumed as springs	interactions between elements of the raft, between piles, between raft elements with piles, and piles with raft elements
	Combarieux (1982)	Piled raft unit - flexible raft	interactions based on relative deformations out of pressuremeter foundation - design rules
Very elaborated computer software based methods	Small and Ta (1996)	Finite element approach for the raft and layers of approach for the supporting soil	piled-raft, raft-soil, pile-soil, and soil-soil for a layering soil profile
	Hain and Lee (1978)	Combination of boundary element with finite element approach	pile-pile, pile-soil, pile-raft, soil-soil interactions
	El-Mossallamy (1996)	Completed boundary element coupled with finite element approach	pile-pile, pile-soil, pile-raft, soil-soil interactions
	Ottaviani, Wang (1995)	3D finite element approach	in principle all types of interactions possible

subcommittee of TC-18 - Prof. O'Neill. This survey is added to the TC-18 full report as enclosure 1, to Part I.

CONCLUSIONS OF THE COMPARATIVE CASE STUDY ANALYSIS

In this particular case study of a piled raft foundation for the central pier of a bridge, presented in the full document, the pile group represents piles as stiff bearing elements and not as settlement reducers.

Thus, the soil under the raft is not mobilized to a large extent to participate in sharing the total load between the piled raft elements, the raft and the pile group.

The measured settlement till November 1995 was of the order of 42 mm. The minimum predicted value of the settlement (26 mm) and the maximum one (68 mm) represent a difference of ± 50 % from the measured one.

The average pile working load is very low considering the actual pile capacity in the group. The maximum recorded pile load was of approx. 1.3 MN for the corner piles. The maximum estimated allowable pile load however was of 2.78 MN.

This comparison between the measurements and the predicted values in the analysis of a piled raft behaviour, applying different methods (from the simplest to the most complicated ones) should be fully elaborated, gathering the contributions from other experts on the same or new well established case records.

Furthermore, updating the measurements on the piled raft is required to develop a real feeling for the most important parameters influencing a piled raft behaviour.

Some valuable conclusions with possible future recommendations for applying each of the discussed methods were included, finalizing the TC-18 after the workshop in Ghent, April 1997.

PART II : DESIGN AND PERFORMANCE

The multiple pile type in use all over the world are conventionally classified in two main categories : the displacement

Table 2. Screw piles

Soil displacement during penetration	Soil excavation during penetration
Prefabricated pile type (torque ≤ 70 KNm)	Partial flight auger on steel casing
Lost auger head + regained casing type	(second generation)
- Screwing down (second generation)	- prefabricated
pulling up	- cast-in-situ
- Screwing down (third generation)	Continuous flight auger (first generation)
screwing up	- small Ø stem, cast-in-situ
	- large Ø stem, cast-in-situ
Variety of pile systems in each cast-in-situ sub-groups due to the various methods for pouring the concrete	
- contractor method	
- under additional hydraulic pressure (Stasol, PCS)	
- combined with expansive mortars (SES)	
- additional grouting under pile tip (Bauer)	
- expander body pile tip (Soilex)	
- Combined with driven pile tip (VB-auger)	
- Combined with prelocated pile tip (Presso-drill)	

Table 3.

Main influencing installation parameters for screw piles

- Soil type as related to pile dimensions
(L/ϕ_{piles}) ↔ cohesive ↔ high water table ↔ normally consolidated
- Installation energy
- Shape of auger head
- location of turn (or screwing) table (↔ torque)
- Type of concrete (W/C)
- uplift acceleration ↔ casting concrete method
- Δ Temperature of auger tip ↔ (W/C)
- general required pile geometry (rough/smooth shaft, 'flanges' continuous or not, ...)

and non-displacement piles (table 2). Such classification should be reviewed in our opinion. Indeed, the definition of 'soil displacement' is hardly scientifically backed up ; it predominantly reflects the pile contractor's point of view on the executional aspects of that specific pile type. However, hardly any real control of the change in stress conditions around the pile, after installation, are supporting such definitions (table 3). Future developments in deep foundation analysis should preferably implement such considerations, the more since deep foundation performance is related to a high extent to soil site parameters after the pile group installation.

Discussing the recent developments in deep foundation techniques, and besides of novelties in pile type and technologies, the todays' approaches for design interconnected with the new ideas for pile installation monitoring and pile testing have to be evidenced.

About the pile type technological advances (Van Impe 1991, 1996, 1997) it can be mentioned that especially the screw pile

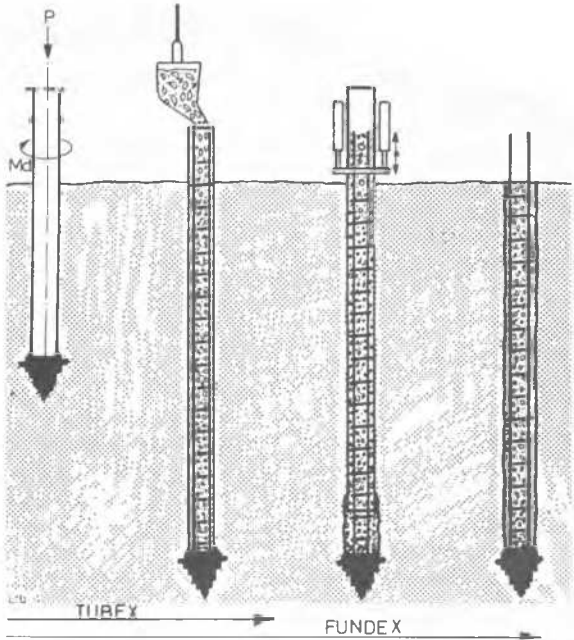


Figure 4. Funдекс screw pile

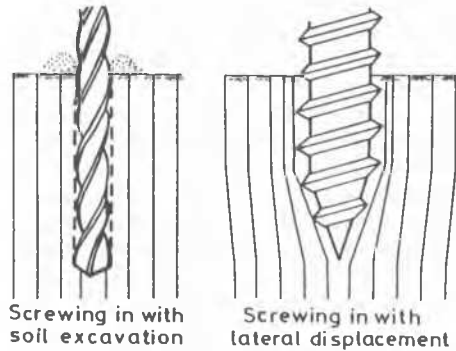


Figure 3. Different types of screwing

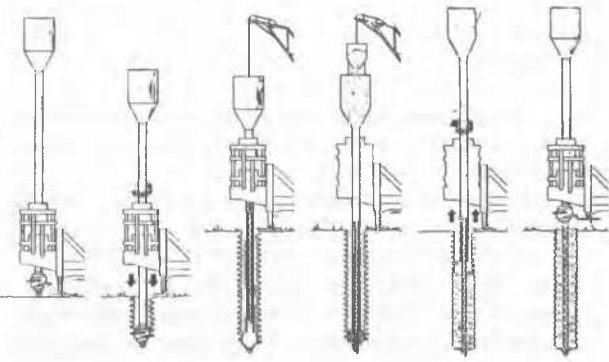


Figure 5. Atlas screw pile

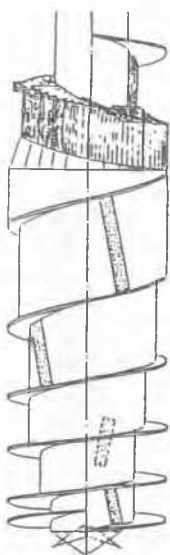


Figure 6. Socofonda Omega-pile

applications have made headway, mainly because of the vibrationless installation feature.

The first screw or auger pile generation (dating from the early sixties), was mainly grafted on the principle of soil excavation during penetration of the auger (fig. 3), so allowing for rather slow pile installation rates and a limited overall torque of 50 kNm to 100 kNm.

The second screw pile generation emerged during the seventies as 'single' lateral displacement type of screw piles, such as the wellknown Fundex screw pile (fig. 4). The capacity was extended tremendously ; the installation energy increasingly adapted up to torques of the order of 500 kNm in combination with or downward vertical thrust.

Only at the beginning of the eighties, the third screw pile generation hastened a break through in the lasting reluctance towards the application of this type of deep foundations. The so called 'double'-action soil displacement screw piles (Franki-Atlas, fig. 5 and Socofonda-Omega, fig. 6) embraced important basic features such as : twofold soil displacement during pile installation and a strict limitation of soil coming up.

The successful further development of the screw pile technique however is hampered by the appreciably uncommon sensitivity of the screw pile quality to installation parameters' variability, table 3 (Van Impe 1996).

The design and performance of various type of screw piles are discussed in the full TC-18 report.

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