INTERNATIONAL SOCIETY FOR
SOIL MECHANICS AND
GEOTECHNICAL ENGINEERING

This paper was downloaded from the Online Library of the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE). The library is available here:

https://www.issmge.org/publications/online-library

This is an open-access database that archives thousands of papers published under the Auspices of the ISSMGE and maintained by the Innovation and Development Committee of ISSMGE.

Effects of reaction piles in axial pile tests

Effets des pieux réaction dans des essais de portance axiale des pieux

J. Latotzke, D. König & H. L. Jessberger – *Ruhr-Universität Bochum, Germany*

ABSTRACT: This paper deals with the interaction mechanisms effecting the in-situ testing of axial loaded piles using reaction piles to transfer the adopted load to the surrounding soil. The influence of this load transfer is investigated concerning the load-settlement behaviour of the test pile. For this purpose centrifuge model tests are conducted, modelling an idealized in-situ test procedure (test pile pushed down, four reaction piles pulled), as well as the loading of a non-influenced single pile. The comparison of the test results shows a significant difference between the load-settlement behaviour observed by modelling the in-situ procedure and the load-settlement behaviour of the single pile without interaction effects. The differences in skin friction and tip resistance are discussed.

RESUME: Cet essai s'occupe des mechanismes interactifs qui influencent les tests in-situ de portance axiale pour lesquelles des pieux de réaction sont utilisés pour détourner la charge appyée vers la terre entourante. L'influence de cette détournage sur les tasseement sous charges du pieu testé est examinée. Pour cette raison des tests modèles avec des centrifugeurs sont executés: premièrement un arrangement d'un test in-situ idéalisé (pieu de test pressé vers le bas, quatre pieux de reaction tirés), deuxièmmement la charge d'un seul pieu non-influencé. La comparaison des résultats des tests montre une grande différence entre les rélations d'appyance de charge pour l'arrangement in-situ et l'arrangement avec le seul pieu sans effets interactifs. Les différences dans la résistance laterale unitaire et la résistance de pointe sont discutées.

1 INTRODUCTION

For the conduction of axial load tests on bored piles heavy loads have to be superimposed to the test pile. Different methods to apply these heavy loads on the test pile are shown in Figure 1. Often the system in Figure 1a is used. In this case a steel girder is installed as a support for the hydraulic jack that loads the test pile. This girder is anchored by reaction piles which transfer the reaction forces to the soil. If the test pile is pushed with a certain load, the reaction piles are pulled with a load of the same size.

The load transfer of the test pile and of each reaction pile to the soil effects the state of stress in the soil surrounding the respective pile. This effect decreases with increasing distance from the pile. If the effected zones are overlapped there is a mutual influence between test pile and reaction piles, which quantity depends on the distance between the piles. This interaction influences the load-settlement behaviour of the tested pile.

The existence of these interrelations is known (van Weele 1982, 1993) but the intensity and significance according to the evaluation of pile load tests is not jet completely understood. This causes an uncertainty of pile load tests with reaction piles concerning the choice of the pile distance and the interpretation of the measured load-settlement behaviour. In a similar manner the described influences are also relevant for the other in situ test methods shown in Figure 1. In this paper we concentrate on the method according Figure 1a.

In order to evaluate the influence of the interaction between test pile and reaction piles it is necessary to know the load-settlement behaviour of the test pile without the influence of reaction piles. For this purpose two kinds of studies have to be carried out: The loading of an uninfluenced single pile (single pile system) and the synchronous loading of a test pile and a group of surrounding reaction piles (combined pile system).

In a field test it seems to be difficult to transfer the reaction forces in a way, that the tested pile is not influenced. It also seems to be difficult to ensure comparable boundary conditions for both kinds of tests. Using a physical model it is possible to avoid these difficulties.

Due to that, centrifuge model tests are carried out at the Ruhr-Universität Bochum to investigate the interaction between test pile and reaction piles. Centrifuge model tests offer the great advantage to model the in-situ stress conditions in the soil.

The aim of the investigation is to determine the influence of the load transfer of reaction piles to the soil on the load-settlement behaviour of the test pile considering several pile lengths, pile spacings and types of soil. By the development of skin friction and tip resistance with the loading procedure the mechanisms of the interaction between test pile and reaction piles will be analysed. Finally a method for the correction of the results of in-situ pile tests is intended to develope.

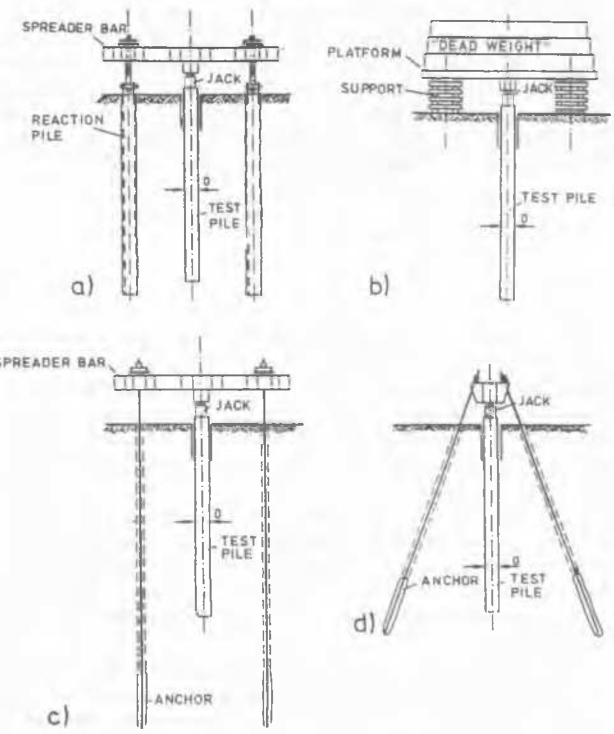

Figure 1. Examples for methods of field pile testing (DGEG 1992).

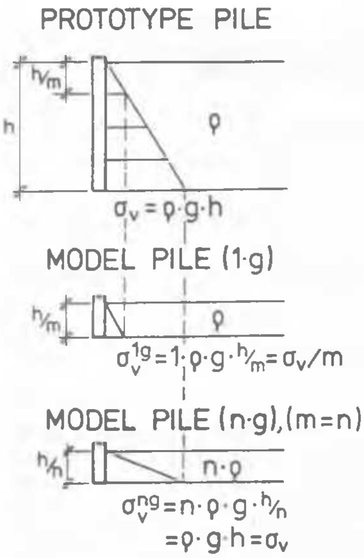

Figure 2. Stress levels in prototype and model.

In this paper results of two kinds of tests are presented. The pushing of a single test pile without any influence of reaction piles and the modelling of the interaction between the pushed test pile and the pulled reaction piles. In these tests the pile arrangement and pile length are kept constant.

The result of this two kinds of tests are compared concerning the load settlement-behaviour of the test pile. From this comparison the effect of the reaction piles on the load settlement behaviour of the test pile is discussed.

2. CENTRIFUGE MODEL TECHNIQUE

The stress-strain behaviour of soil is not linear and depends on the stress level increasing with depth. If soil-structure interaction is investigated by physical modelling it is important to model the correct stress-strain relationship and the correct stress level.

Using centrifuge model testing the scaled model (scale 1 : m) of a prototype (full scale) is exposed to a multiple of the earth gravity 'n•g'. If n is chosen to be the scaling factor of the model (m = n) all mass forces of the model are increased in a way that the state of stress in the model and in the prototype is identical at similar positions (Figure 2), see Schofield (1980). The tests described in this paper have been performed in the Bochum Geotechnical Centrifuge Z1 (Jessberger & Güttler 1988).

3. TEST DESIGN

3.1 *Single pile system*

Figure 3 shows the model set-up for a single pile system with one test pile. This system is used to determine the load-settlement behaviour of the test pile without the influence of reaction piles.

The model pile has a diameter of 30 mm and an embedded length of 220 mm. Applying a g-level of n = 45 a prototype pile with a diameter of D = 1.35 m and an embedded length of L_E= 9.9 m is modelled.

The model piles are made from a steel tube with a wall thickness of 1 mm. The roughness of the surface is increased by gluing it with sand. By this a soil-pile interface may be modelled similar to bored piles. The model pile is placed in the centre of a circular strong box embedded in fine, dense sand. The parameters of the soil are given in table 1.

After spinning up the completed model placed in the centrifuge to the selected g-level of n = 45 the test pile is pushed down by a hydraulic jack with a very slow linear load function of 0.324 MN/h concerning the prototype. The jack is fixed on a spreader bar that transfers the reaction forces to the walls of the strong box.

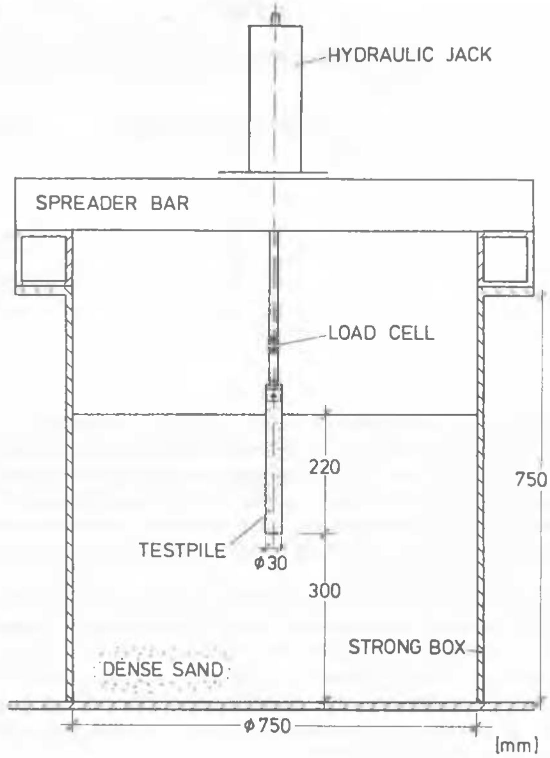

Figure 3. Test design for the single pile system.

Table 1. Parameters of the model sand.

density of solid particles ρ_s	2.66	kN/m³
minimum density of soil ρ_{min}	1.39	kN/m³
maximum density of soil ρ_{max}	1.68	kN/m³
minimum void ratio of soil e_{min}	0.91	-
maximum void ratio of soil e_{max}	0.56	-
angle of internal friction φ'	40	°
avarage diameter of solid particles d_{50}	0.22	mm
uniformity coefficient U	2.09	-

The settlement of the pile is measured by an LVDT located inside the jack. The total load acting on the pile is measured with a load cell. Additionally the distribution of skin friction with depth is measured with strain gauges applicated on the inner side of the pile and the tip resistance is measured separately with a force transducer.

3.2 *Combined pile system*

Figure 4 shows the test design of the combined pile system to model the in-situ pile test with one test pile and four reaction piles. The geometrical arrangement of the piles is presented in Figure 4b. Here the clear pile distance is about 4 times the pile diameter. The dimensions of the reaction piles are equal to the dimensions of the test pile.

To realize the in-situ loading of test pile and reaction piles in the model a special loading mechanism has been developed. This mechanism makes it possible to load the test pile and the group of four reaction piles separately but synchronous with two hydraulic jacks. The upwards directed loading of the reaction piles is achieved by loading a steel rope that is steered around on several rolls and finally hinge-connected on both ends with two reaction piles mounted at a little steel bar. With this mechanism an uniform distribution of the load on each reaction pile is ensured.

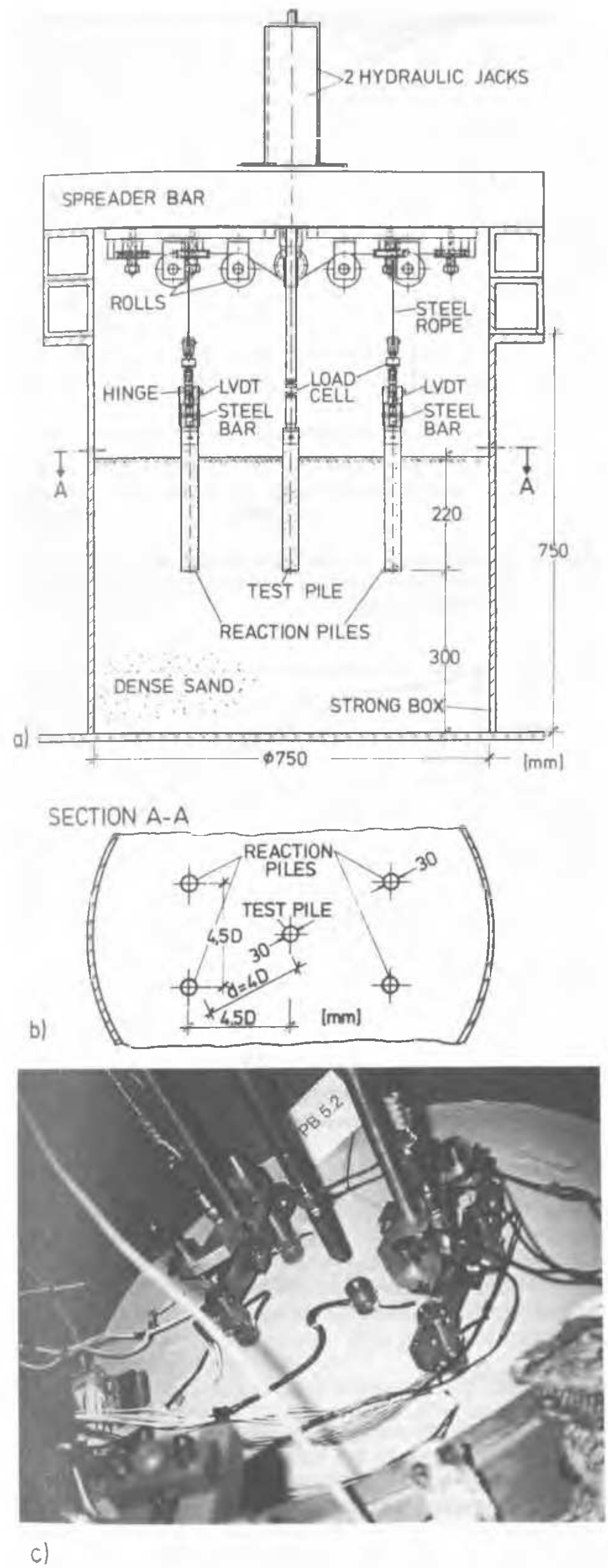

Figure 4. Test design for the combined pile system.

The complete model is placed in the centrifuge and the centrifuge is spinned up to the target speed to produce an acceleration of 45• g. The test pile is loaded downwards by one of the hydraulic jacks just like the single pile in Figure 3. Simultaneously a second jack loads the group of test piles upwards with the described mechanism. The loading procedure is shown in Figure 6.

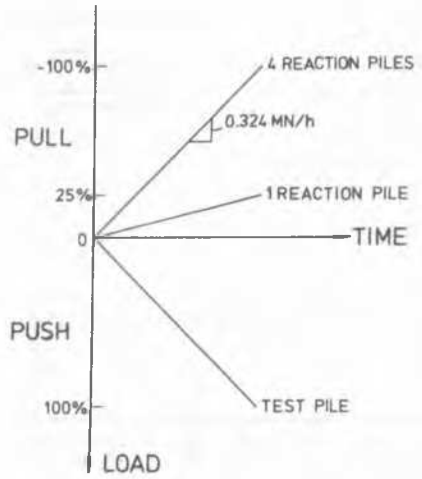

Figure 5. Loading procedure of test and reaction piles (prototype scale)

The total load, skin friction and tip resistance as well as the settlement of the test pile are measured as described in chapter 3.1. The total load of the reaction piles is measured with two load cells mounted between the end of the rope and the little steel bar. The skin friction distribution of the reaction piles is measured with strain gauges applicated on the inner side of the piles. The displacement of the reaction piles is measured with an LVDT placed on the top of each reaction pile.

4. RESULTS

All test results are presented in the prototype scale. The g-level of all presented tests is n = 45.

4.1 *Single pile system*

The load-settlement behaviour of a single pile observed in three centrifuge model tests are shown in Figure 6. The total load Q acting on the pile is plotted versus the dimensionless settlement (s/D). The maximum difference of the test results related to the average is less than 4% regarding equal settlements. These results demonstrate the reproducibility of the tests and give a reliable reference to indicate the influence of reaction piles on the test pile by comparing the load-settlement behaviour.

One load-settlement curve is separated in skin friction Q_S and tip resistance Q_T in Figure 7. The results can be described as follows:

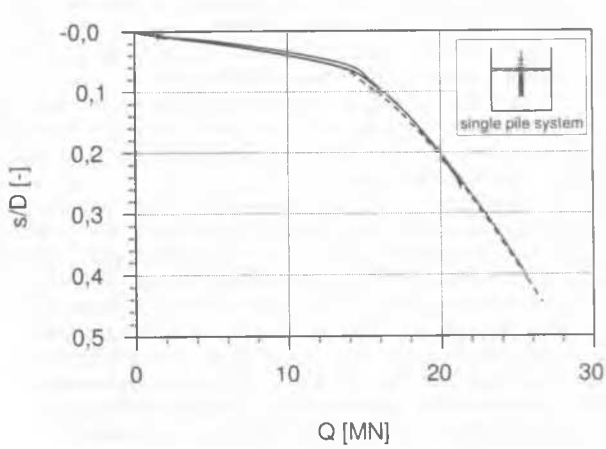

Figure 6. Load-settlement behaviour of test piles observed from the single pile system.

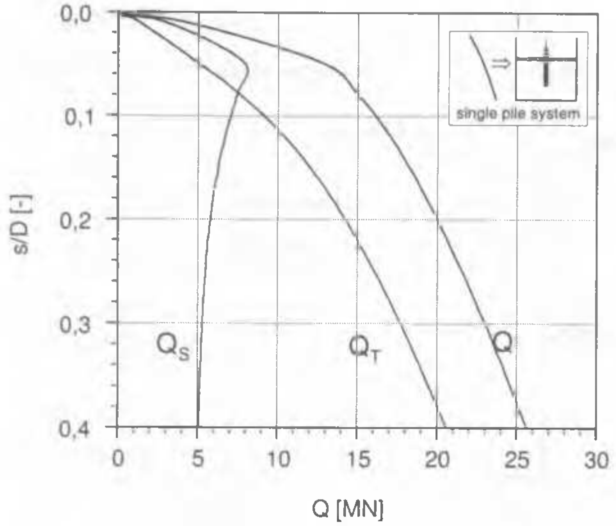

Figure 7. Development of total load, skin friction and tip resistance of a test pile observed from the single pile system.

- The tip resistance-settlement behaviour $Q_T/(s/D)$ is a curve with increasing declination that leads to linear behaviour without yielding a failure.
- The skin friction-settlement behaviour $Q_S/(s/D)$ shows an maximum that marks the failure. After reaching this maximum the friction decreases and converges to a residual value. This behaviour is typical for the friction mechanism in a dense soil. With increasing displacement in the friction surface the soil is loosening. At the peak the soil particles pass each other and finally sliding takes place.

4.2 *Combined pile system*

Figure 8 shows the load-settlement behaviour of a test pile from a test with the combined pile system, taken into account the interaction between test pile and reaction piles.

The load-settlement behaviour can be described as follows:

- The bearing capacity of the test pile observed from the combined pile system is higher than the bearing capacity observed from the single pile system concerning equal settlements.
- Regarding settlements from s/D > 0.05 to s/D = 0.4 there is a maximum difference of Q between the single pile system and the combined pile system of about 1.5 MN.
- More remarkable is the effect of reaction piles in the combined pile system up to a settlement of s/D = 0.05. For such settlements the absolute grows up to a maximum value of about 4 MN.
- The influence of the reaction pile leads to an increase of tip resistance up to a maximum difference of 3.8 MN at a settlement of s/D = 0.05. From s/D = 0.05 the absolute difference decreases with increasing settlement.
- The development of skin friction with settlements of the test pile influenced by the reaction piles shows a similar characteristic as the skin friction of the test pile from the single pile system described above.
- The influence of the reaction piles leads to smaller settlements necessary to activate the maximum skin friction (s/D = 0.02 compared to s/D = 0.056 of the single pile), and to a lower maximum of the activated skin friction (6.4 MN to 8 MN for the single pile). This is clearly shown in Figure 9.
- After reaching the maximum at s/D = 0.02 the skin friction observed from the combined pile system converges faster to a residual value than the skin friction of the uninfluenced pile. This leads to the fact that the effect on the skin friction caused by the influence of the reaction piles can be devided in two sections: An increase of the skin friction for settlements smaller than s/D = 0.03 and a decrease of the skin friction for settlements larger than s/D = 0.03.

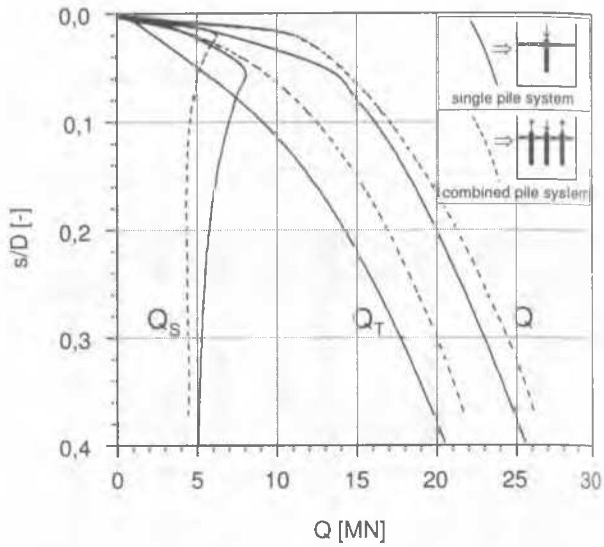

Figure 8. Development of total load, skin friction and tip resistance of test piles observed from the combined pile system and from the single pile system.

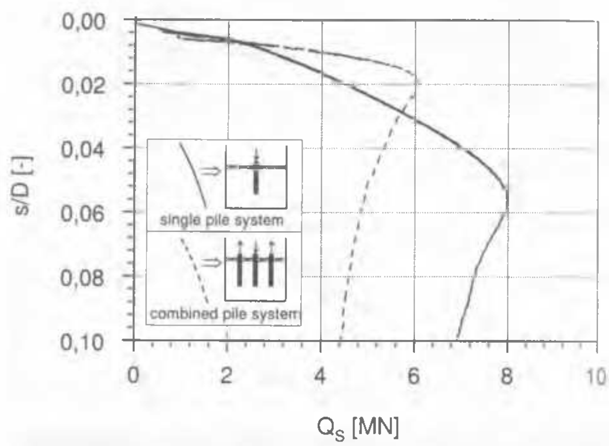

Figure 9. Development of skin friction with settlements of the test piles observed from the combined pile system and the single pile system.

- As the influence on the total bearing capacity is the superposition of the influences on skin friction and tip resistance, a more significant increase of the bearing capacity of the test pile takes place for settlements smaller than s/D = 0.03 as for larger settlements.

5. DISCUSSION

A significant influence of the reaction piles on the load-settlement behaviour of the test pile is observed from the test results, clearly shown by plotting the influence factors f, f_S and f_T versus settlement s/D in Figure 10.

The total bearing capacity of the test pile is highly influenced by the reaction piles concerning small settlements. An increase of skin friction and tip resistance takes place for such settlements. For larger settlements the skin friction is reduced by the influence of the reaction piles what leads to a smaller influence on the total bearing capacity.

The behaviour of the test pile up to settlements of s/D = 0.1 is relevant for practical design. For these settlements the influence of the reaction piles on the test pile may lead to a measured bearing capacity of nearly 70% larger than the bearing capacity of the uninfluenced single pile. Due to this it seems to be necessary to analyse the interaction between test pile and reaction piles more in detail.

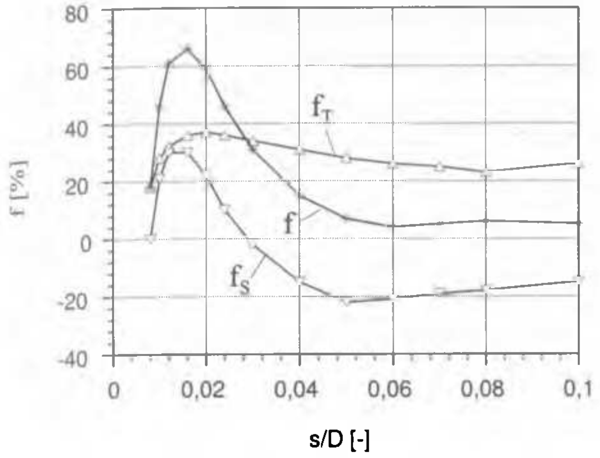

Figure 10. Development of the influence factors f, f_S, f_T with settlements.

$$f = \frac{Q_{CPS} - Q_{SPS}}{Q_{SPS}} \quad (1)$$

$$f_S = \frac{Q_{S,CPS} - Q_{S,SPS}}{Q_{SPS}} \quad (2)$$

$$f_T = \frac{Q_{T,CPS} - Q_{T,SPS}}{Q_{SPS}} \quad (3)$$

where:

Q = total load , Q_S = skin friction , Q_T = tip resistance
SPS = single pile system , CPS = combined pile system

The investigations have to be focused on the identification of the mechanisms causing the rapid activation of skin friction with small settlements, the lost of maximum skin friction and the increase of tip resistance. In order to understand these mechanisms it will be helpful to study the influence of pile distances and pile lengths on the interaction.

6. CONCLUSIONS AND OUTLOOK

Centrifuge model tests have been performed to investigate the interaction mechanisms effecting the in-situ testing of axial loaded piles using reaction piles to transfer the adopted load to the surrounding soil. The load-settlement behaviour of a test pile has been determined by modelling an idealized in-situ test procedure (test pile pushed down, four reaction piles pulled), as well as the loading of a non influenced single pile

The test results show a significant influence of the reaction piles on the test pile. Especially for settlements smaller than s/D = 0.1, relevant for practical design, an influence of the reaction piles on the load settlement behaviour of the test pile of nearly 70% can be observed.The effect of the reaction piles on the development of skin friction and tip resistance of the test pile is described.

However, the presented work shows that centrifuge modelling is a powerful tool to investigate this task. By the use of this technique it is possible to determine the load settlement behaviour of the test pile without interaction mechanism and with influence of reaction piles on equal boundary conditions.

Further work has to be focused on parameter studies concerning e.g. pile distance, pile length and several soils and on the development of a mechanical model. With this model it may be possible to estimate the correction of bearing capacity measured in axial field pile tests.

7. REFERENCES

Empfehlungen des Arbeitskreises 5 der DGEG 1992. *Statische axiale Pfahlprobebelastungen von Pfählen.* Technical report.

Jessberger, H.L. & U.Güttler 1988. Bochum geotechnical centrifuge. *Proc. of the Int. Conf. of Geotechnical Centrifuge Modelling, Centrifuge '88, Corté. J.f. (ed.), Paris:* 37- 44. Rotterdam:Balkema.

Schofield, A.N. 1980. Cambridge geotechnical centrifuge operations. *Geotechnique,* Vol.20: 227-268.

Van Weele A.F. 1982. Which load is allowable on a given foundation pile, when its actual load-settlement behaviour is available through a load test?. *Amici et Alumni, EM. Prof. Dr. Ir. E. E. de Beer.* 287-296.

Van Weele A.F. 1993. Keynote lecture: Quality assessment foundation piles after installation. *Proc. 2nd Int. Geotechnical Seminar on Deep Foundations on Bored and Auger Piles, Ghent,Belgium, 1993:* 459-467. Rotterdam: Balkema.