Proc. XIII ECSMGE, Vaníček et al. (eds). © ČGtS, Prague, ISBN 80-86769-01-1 (Vol. 2)

Experience with friction-micropiled-raft foundation on soft soils

Une expérience avec la micropieux-base de frottement dans les sols mous

H.-G. Kempfert & F. Böhm,
University of Kassel, Institute of Geotechnics, Kassel, Germany; geotech@uni-kassel.de

KEYWORDS: friction-micropiled-raft foundation, maintained load grouted pile test, settlement, soft soil

ABSTRACT: A new foundation system for buildings on soft soils using micropiles is reported in this paper. The presented friction-micropiled-raft foundation has successfully been realised for new buildings on soft soils to stabilise the underground and reduce the settlement. An exemplary comparison of practical projects in terms of measured settlements of a raft foundation with the friction-micropiled-raft foundation on normal consolidated soft soils has proven the effectiveness of the new foundation system.

RÉSUMÉ: Le papier présente une solution pour construire les fondations des bâtiments sur les sols mous avec micropieux. La fondation avec les micropieux flottants a été construit avec succès dans nouveaux bâtiments sur les sols mous pour stabiliser le sous-sol et pour réduire le tassement. L'efficacité du nouveau système est confirmée au moyen de la comparaison des tassements des radiers de fondation avec les tassements des fondations avec micropieux dans plusieurs constructions sur les sols mous normal consolidées.

1 INTRODUCTION

Several construction measures have been realised in the southern Germany with a piled-raft foundation with micropiles on soft soils. Beside the stabilisation effect of the new foundation system, a significant settlement reduction against raft foundations could be observed. *Kempfert (1986)* reported about the first positive experiences of successfully strengthening an old railway bridges abutment with the illustrated foundation system.

In particular in urban areas, settlements due to very thick layers of soft soils can negatively influence the neighbouring buildings with shallow foundations, for example additional settlements due to newly built structures. Such settlements can lie within the range of decimetres. The new foundation system presented in this paper enables to limit settlements to an admissible size, hence limiting possible negative influences on neighbouring buildings.

A research project financed by the central public funding organisation for academic research in Germany (DFG) is under way at the Institute of Geotechnics, University of Kassel, covering all aspects of the bearing capacity of injection micropiles on soft normally consolidated soils. In the present paper the effectiveness of the friction-piled-raft foundations with grouted micropiles is illustrated based on case studies of practical projects.

Micropiles were originally designed by the Italian *Lizzi* to support and safeguard foundations at risk and patented in 1952. Since then micropiles have been used world-wide for distinct building measures. *Bruce et al. (1997)* and *Armour et al. (2000)* summarised a report of world wide realised projects such as foundation underpinning, slope stabilisation, slope reinforcement and gravity retaining structures. At present there are just few realised friction-piled-raft foundation on soft soil reported in literature.

Examples of building foundations with micropiles found in literature are mainly deep foundations, where the pile toe penetrates the underlying bearing layer. An overview of foundations on soft soils in Mexico city is given by *Auvinet (2002)*. He investigated the reaction of the foundation system to seismic excitation in addition to the static loads.

Over the years, different types and manufacturing methods of micropiles were invented. The piles discussed hereafter are of the GEWI type, DYWIDAG System (see *DSI (2002)*)

2 FOUNDATION SYSTEM AND SUBSOIL

Two foundations of neighbouring buildings within the same location are compared hereafter. One of them, located south west (Figure 1), consists of seven independent buildings with up to 4 storeys. The overall outer size of the building is 100 x 42 m and it is founded on raft foundation. A new 4-storey building with mainly two parts and a size of 15 x 43 m is located east of the described building. It is founded on a friction-micropiled-raft foundation with 95 injection type piles.

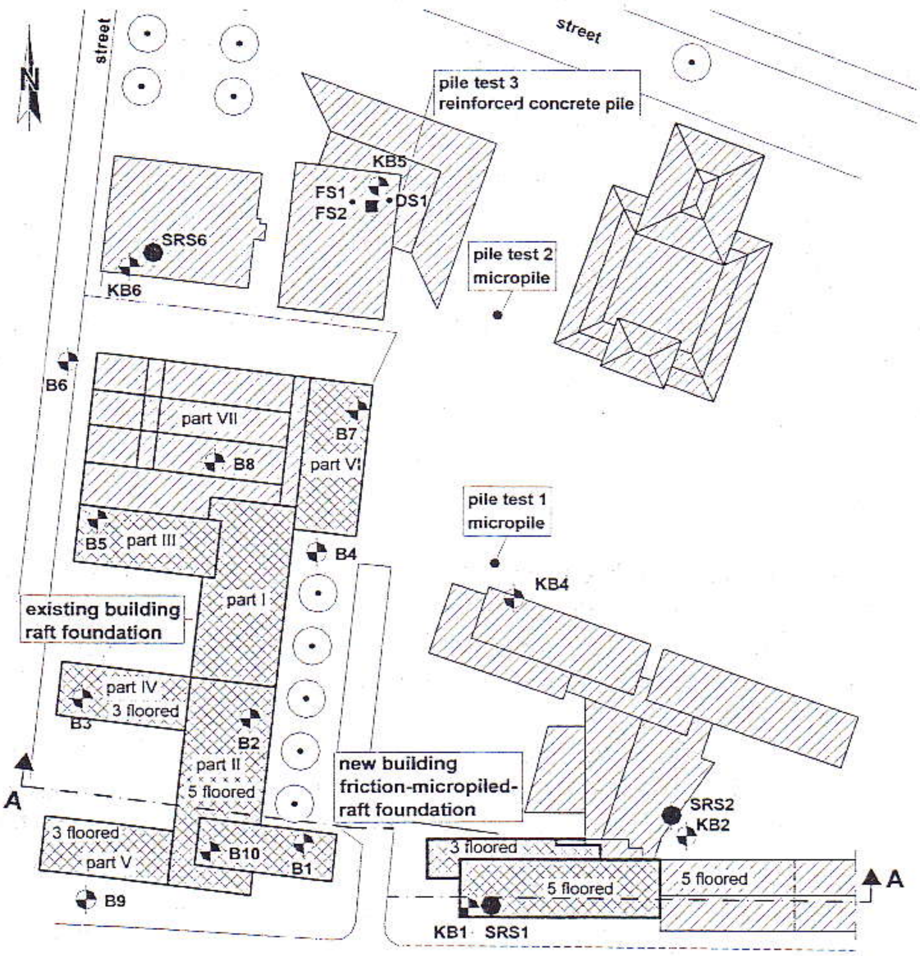

Figure 1. Site map

The micropiles with a length of 16.25 m (GEWI-pile, DYWIDAG System) each and a diameters of 150 mm were installed in a drilled hole with casing in a grid of 2 to 3 m. Then the piles were grouted under pressure of 25 to 30 bar at a depth of 9 m and 14 m below the ground surface. A second pressure grouting was carried out once more with pressures of 27.5 to 38.5 bar. Figure 2 shows a typical cross sections of the investigated buildings and foundations.

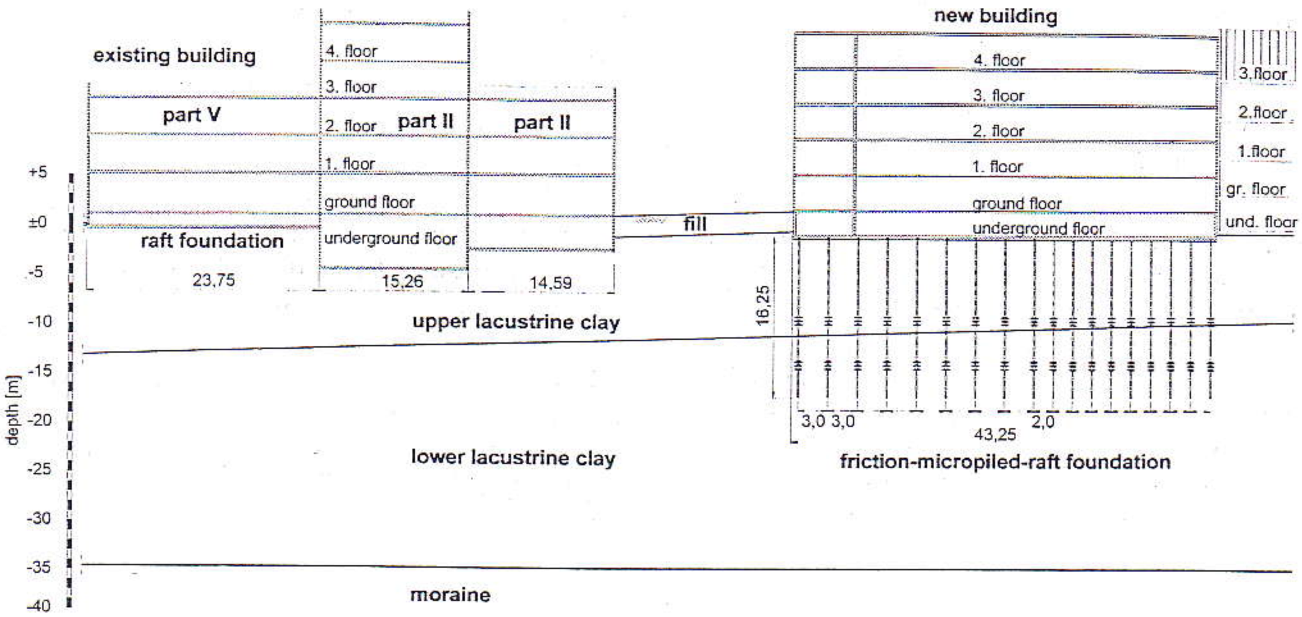

Figure 2. Cross section and subsoil profile (section A-A)

The ground condition encountered in the southern Germany around lake Constance consists of normal consolidated soft soils which extends up to a depth of 60 m. The site investigation at the site (Figure 2) revealed a 2 - 3 m made ground overlying a very young normally consolidated soft soil layer, consisting of clayey silts with pulpy to soft consistency and some organic components. This soil material is described hereafter as upper lacustrine clay. At a depth of 12 to 15 m below surface, a transition layer from upper lacustrine clay to a lower lacustrine clay can be observed which consists of soft to stiff clayey silts with inclusions of thin horizontal fine sand bands. Beneath the lower lacustrine clay layer a moraine layer consisting of clayey silts with large components of sand and boulder was encountered at a depth of 24 to 36 m.

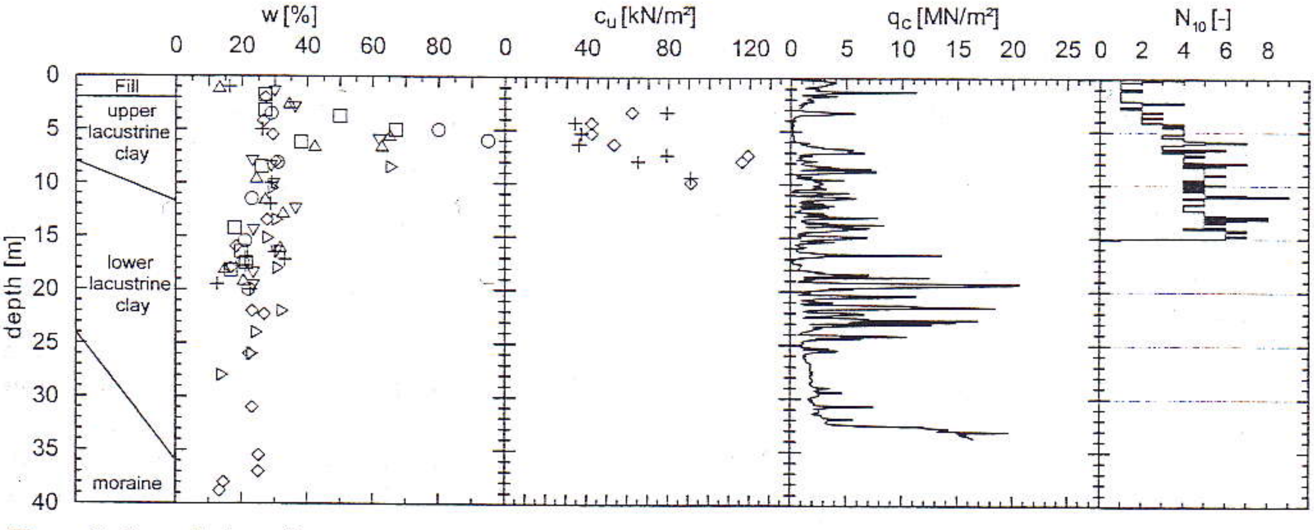

Figure 3. Compilation of water contents, vane shear tests, penetration tests and heavy penetration tests

A water contents around 30 %, and partly up to 90 % was measured both in the upper lacustrine clay and lower lacustrine clay (Figure 3). The same figure shows a diagram of two field vane test, a typical cone penetration and heavy penetration test results. The average number of blows in the upper lacustrine clay was N_{10} = 5and the maximum measured was N_{10} = 9.

3 SETTLEMENT

Settlement gauges were installed at different location of the buildings, in which settlements of the raft foundations were evaluated from the inclination measurement of the individual buildings. The contact pressure lies between 50 to 70 kN/m². A back analysis result shows a settlement values between 40 to 180 mm. Figure 4a shows settlements of the individual buildings with raft foundation.

The contact pressure under the friction-micropiled-raft-foundation lies around 70 kN/m². Measured maximum settlements at building corner points was 17 mm, whereby the foundation have not ceased to settle so far. Extrapolated total settlements according to *Sherif* amounts to about 18.2 mm. The measured and calculated settlements of the buildings with the friction-micropiled-raft-foundation are shown in Figure 4b.

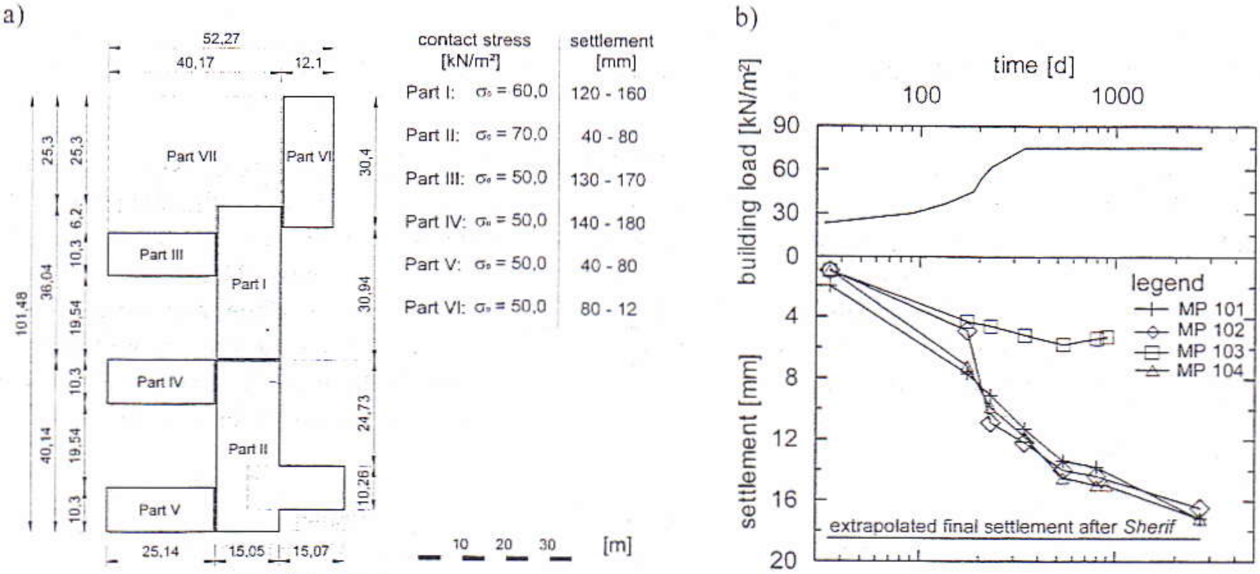

Figure 4. a) Top view and settlement of raft building b) Settlement measurement of friction-micropiled-raft foundation

4 PILE TEST RESULTS

The skin friction of a single pile (GEWI-pile, DYWIDAG System) in soft soils was estimated from pile tests under tension forces. The observed pile head displacement of two pile tests are presented in Figure 5.

A maximum pile resistance of 432 kN was measured from the pile test 1 with a pile length of 15.5 m. The unrecoverable settlement after force removal amounted to 32.1 mm (Figure 5a). A further pile test on a 14.7 m pile showed a maximum pile resistance of 800 kN and unrecoverable settlement of 7.8 mm (Figure 5b). Similar pile tests showed a maximum pile resistance of about 800 kN.

Alternatively a pile load test under compression was carried out on a 32 m long reinforced concrete pile (300 x 300 mm), in order to investigate the usability of such piles as friction piles. The pile itself consisted of three separate parts with a length of 9 m, 14 m and 9 m. Such construction had been chosen in order to conduct a dynamic test of the pile interconnections. The pile was driven up to a depth of 7 m without any major driving energy. Between a depth of 3 and 7 m, a pile slip without noticeable friction was observed in areas of low shear strength. The driving energy required and the number of blows are shown in Figure 6.

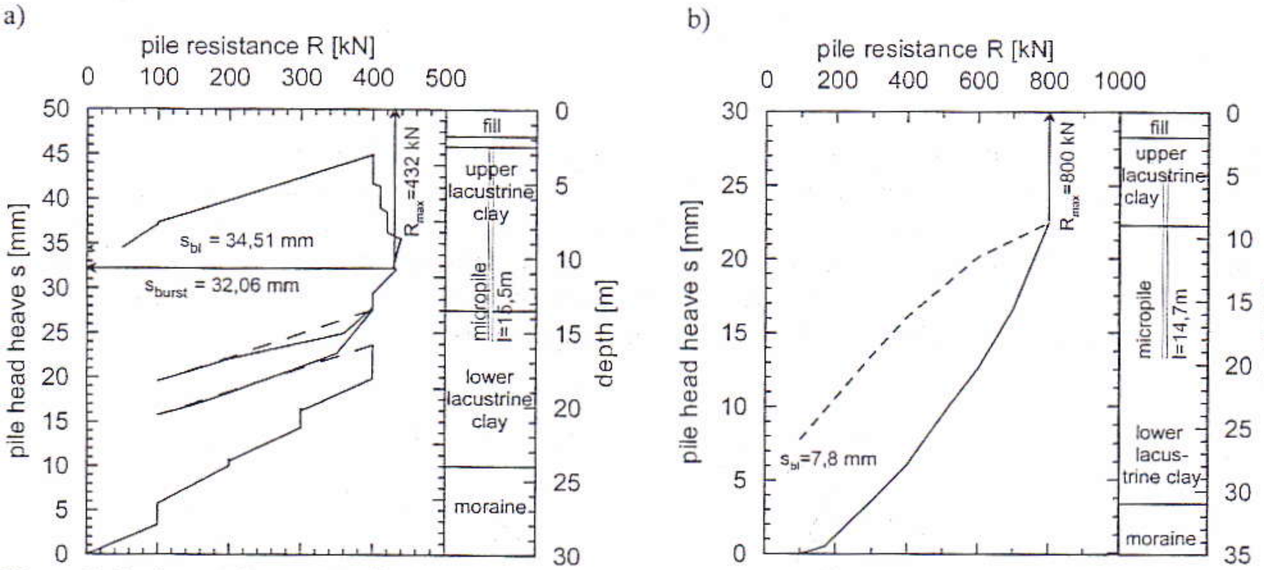

Figure 5. Resistance heave; a) pile test 1 b) pile test 2

The dynamic pile load tests were carried out by means of the CASE and CAPWAP methods. The test results were analysed at different penetration depths of the reinforced concrete pile. Figure 6 shows the test results as well as the idle time after driving the pile to the respective depth. The pile resistance at a depth of around 17.5 m and after 10 min idle time was 400 kN, after 1.5 h it was 600 kN. The increase of the pile resistance is attributed to the dissipation of the pore pressure with time. Further pile load test at a penetration depth of 22 m showed a pile resistant of about 500 kN. At a depth of 31 m, the pile shaft was already 1 m deep in the moraine layer. A pile resistance of about 650 kN was measured immediately after end of pile driving. After further 4 days, the pile was loaded once more and a pile resistance 1150 kN was calculated according to the CASE method and 1050 kN according to CAP-WAP method.

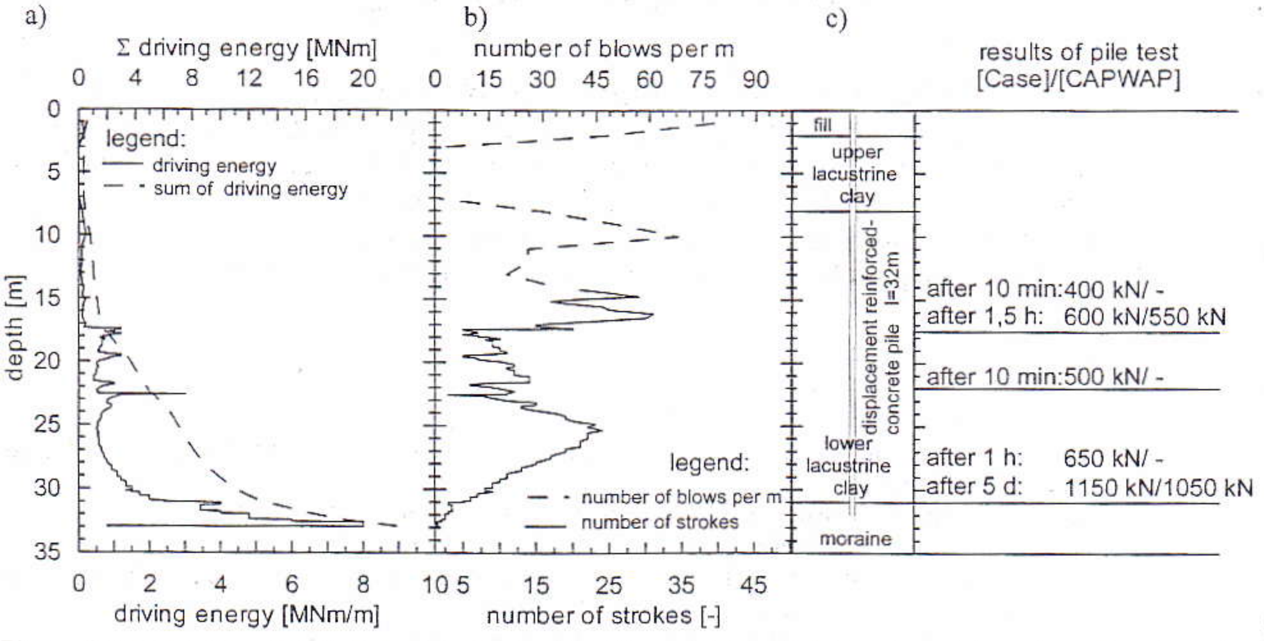

Figure 6. Test loading of a reinforced concrete pile; a) inserted penetration energy; b) number of strokes; c) results of pile tests

A comparable injection 14.7 m pile (ø 150 mm) located immediately next to the dynamic pile load test had shown a pile resistance of 800 kN at a penetration depth of 19.70 m (Figure 5b).

5 SUMMERY

The paper gives a short insight into the application of micropiles in a combined piled-raft foundation on soft soils. The positive experiences with such bearing foundation system could be verified by showing the minimal measured settlement of 17 mm. Moreover, injection piles have proven to contribute in stabilising the surrounding soils. A comparison of measured settlement of a raft foundation and a similar building on friction-micropiled-raft foundation with a similar contact pressure are shown in Figure 7, where the settlements amount 180 mm and 4 mm respectively.

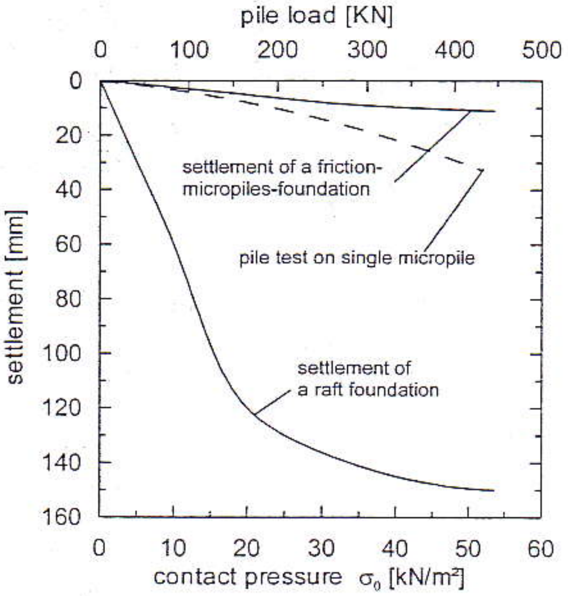

Figure 7. Comparative settlements of a raft foundation and a friction-micropiled-raft foundation

The results obtained from various pile load tests underline the effectiveness of the friction micropiles, which shows a pile resistance of up to 850 kN. Comparative dynamic pile load tests on reinforced concrete piles showed a pile resistance of about 600 kN at a similar penetration depth, at which the pore water pressures were not fully dissipated and hence a reduced pile resistance.

The ample effectiveness of the friction-micropiled-raft foundation systems is due to the prestressing of the soft soil between the piles by the injection pressures during pile manufacturing.

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PROCEEDINGS OF THE XIIIth EUROPEAN CONFERENCE ON SOIL MECHANICS
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Editors/Rédacteurs:
I. Vaníček, R. Barvínek, J. Boháč, J. Jettmar, D. Jirásko, J Salák

VOLUME 2

Papers presented for Main Sessions 4,5,6

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