The Soilex Pile System

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DRAFT
supplied for review and publication at the
8th International DFI Conference in New York
October 5-7, 2000

ABSTRACT

The Soilex Pile combines a slender shaft, for quick and gentle installation, with an enlarged pile toe, for high bearing capacity. The key component is the Expander Body, which is inflated by injecting grout when in position.

The latest development reduces the total cost of Soilex Piles, in many cases competitive to pre-cast concrete piles and displacement piles. Soilex Piles can now be installed on top of a bearing soil layer, instead of 3 – 4 m into that soil as previously, further minimising the disturbance. Soilex Piles achieve high capacity in relatively loose soils, with ultimate loads typically between 1000 – 2000 kN in a sand with CPT qc= 5 – 10 MPa or SPT N= 10 – 20. It is possible to pre-load and proof-load all piles with dynamic testing up to 2000 kN or using built-in jacks, verifying the bearing capacity.

The vibratory installation method, which is extremely quick, causing very little soil disturbance and noise, is exemplified with two cases.

INTRODUCTION

Soilex Piles and Soilex Anchors have been used successfully all over the world during the last 16 years, mostly in soft and medium dense soils. New developments further emphasise on the environmental aspects and also reduce the total piling cost.

Our new ideas consist of installing the piles on top of a bearing soil layer, as shown in Fig. 1, instead of 3 – 4 m into that soil as previously. Since the piles are made shorter it is often no longer necessary to penetrate into dense soil in order to achieve high bearing. The disturbance is minimised by easier and faster installation. This is made possible by loading all piles during construction to eliminate settlements. Preloading can be carried out using a drop hammer, at the same time performing dynamic testing. In underpinning, built-in jacks are used. Load testing of all piles can allow for reduced factors of safety.

Soilex are convinced that this new concept will challenge traditional piling methods and call for more environment-friendly installation methods.

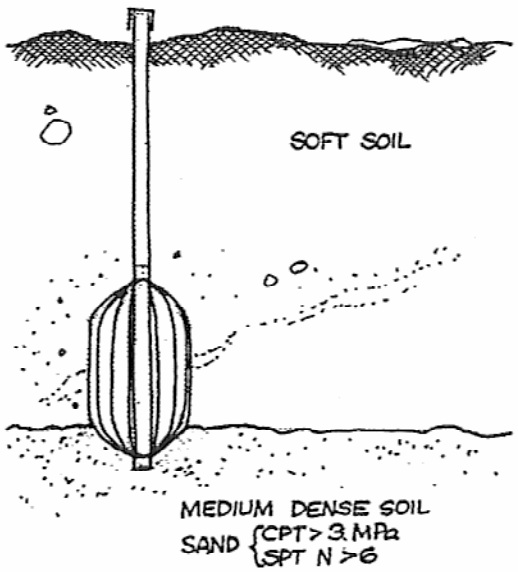

Figure 1. The Soilex Pile is placed on top of a bearing soil layer

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COMPARISON WITH OTHER FOUNDATION ELEMENTS

When used in a pile or anchor application, the Expander Body can be compared to a footing or a dead-man anchor respectively, being the form work as shown in Fig. 2. An important difference is that the Expander Body can be placed virtually anywhere, not requiring excavation. In this way, a solid, concrete body with pre-determined shape and volume can be created at any depth in the ground. Since the "pouring" of concrete can not be seen directly it is important to monitor the inflation of the Expander Body to assure the final size and shape. This is done by measuring the grout pressure and volume.

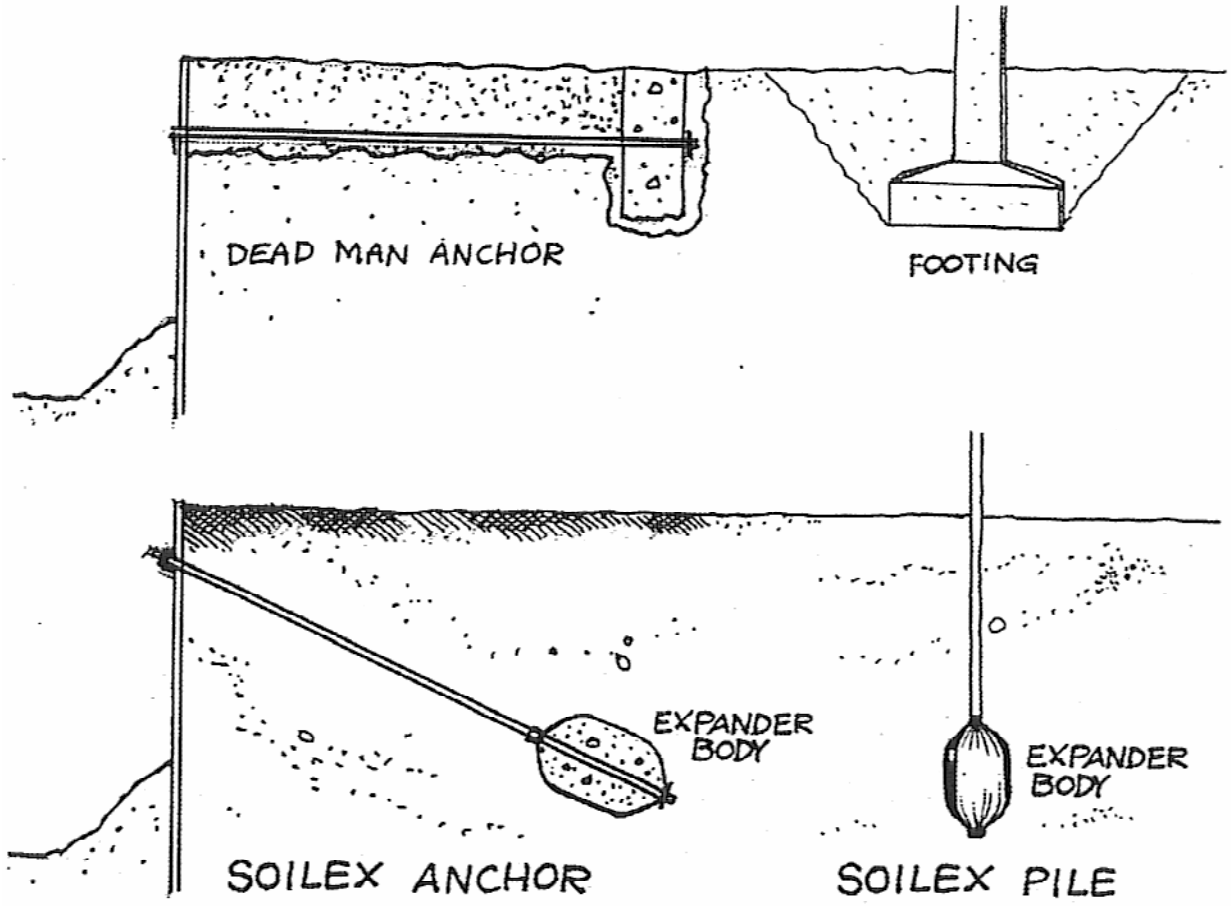

Figure 2. The Expander Body compared to a footing and a dead man anchor.

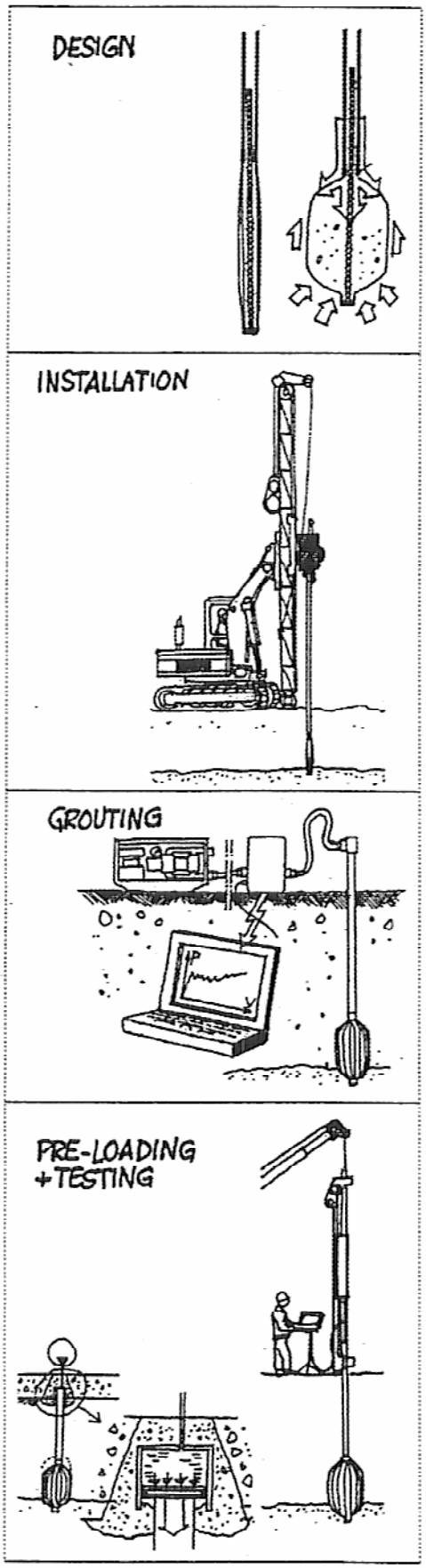

Figure 3. Elements of the Soilex Pile System

SOILEX PILE SYSTEM

The Soilex Pile System (Fig. 3) involves the whole piling process, including design of the pile construction, selection and manufacture of the appropriate Expander Body for a given soil and required capacity, pile installation and expansion of the Expander Body and preloading and testing of the produced pile. Installation and expansion are performed as separate work cycles and can be carried out in parallel

DESIGN

The pile shaft typically consists of a steel pipe welded to the Expander Body. In order to assure that the load is transferred from the pile shaft down to the pile toe, the connection between shaft and Expander Body is reinforced with a bar. For high capacity piles the load is also transferred over a ring to the inflated Expander Body, as shown schematically in Fig. 4.

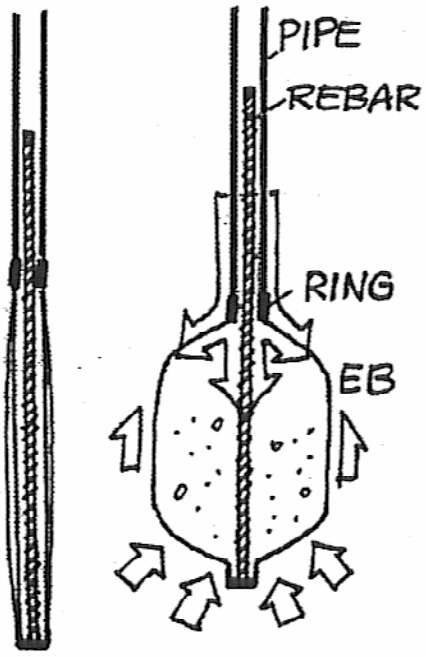

Figure 4. Load transfer through the pile shaft to the bottom of the Expander Body

The whole pipe can be welded to the Expander Body on the building site. Another method is to weld a short piece of pipe during the manufacture of the Expander Body and perform the splicing automatically during installation.

The ultimate soil resistance can be calculated for piles with different sizes of Expander Bodies using Cone Penetration Test results. The

resistance is divided into base bearing and side friction.

$$P_u = P_{EB\text{-}base} + P_{EB\text{-}side}$$
$$= q_c \times A_{EB\text{-}base} \times k_1 + f_s A_{EB\text{-}side}$$

where P_u = ultimate soil resistance
q_c = CPT cone bearing
f_s = CPT sleeve friction
$A_{EB\text{-}base}$ = Expander Body base area
$A_{EB\text{-}side}$ = Expander Body side area
k_1 = scaling factor, see Table 1

Table 1. Scaling factor for calculation of bearing capacity depending on soil type

Soil type	k_1
clay	0.8
clayey silt	0.7
silt	0.6
sand	0.5
gravel	0.5

In soft clay, the undrained shear strength Cu can be used to calculate the ultimate resistance as

$$P_u = 9 \times Cu \times A_{EB\text{-}base} + Cu \times A_{EB\text{-}side}$$

The above equations give lower bound values since the positive effect of soil compaction and consolidation are not accounted for.

INSTALLATION METHODS

The Soilex Pile can be installed in different ways, depending on local practice, soil conditions and specific requirements. Whatever method that you choose, the piles can be installed using rather small and light-weight equipment. Fig. 5 show vibratory installation using a small vibrator and how an existing building is underpinned with jacked piles. The equipment can also be excavator mounted or hanging free from a wire. The pile shaft can easily be spliced to reduce the length of each element, if required.

Foundation piling

Vibratory driving. Soilex Piles do not require driving to refusal and are therefore specially suited for vibratory installation, which is also very quick. Due to the small diameter shaft a relatively small vibrator, of about 900 kg, can be used. Ground vibration can be reduced by adjusting the vibrator frequency and amplitude, if acceptable vibration levels are exceeded on sensitive nearby structures. Prior to placement of the Soilex Piles, holes can be pre-punched with a steel pipe drifter, facilitating the installation of the Soilex Piles. The pre-punching works as a penetration test in all pile locations. In the case that obstructions, such as boulders or timber, are encountered in the ground, alternative pile locations can quickly be found by probing with the drifter. The Soilex Pile, consisting of the Expander Body at the end of a steel pipe, is then vibrated into each pre-punched hole.

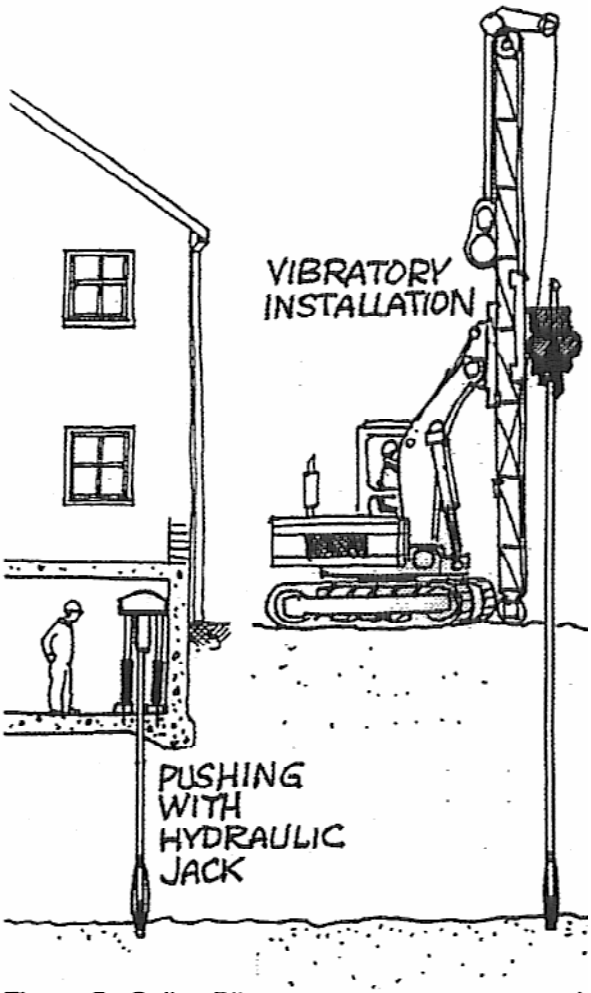

Figure 5. Soilex Piles can generally be installed using small equipment

Impact driving. Compared to other pile types, impact driven Soilex Piles cause relatively little disturbance. This is due to the small diameter shaft combined with the fact that they are made shorter, founded on top of a bearing stratum.

Penetration through dense layers is mostly not required, making the installation easier. Both pneumatic and hydraulic hammers of 150 – 600 kg can be used.

Bored pile. The Soilex Pile can also be adapted to different types of bored piles, normally resulting in a cast-in-place concrete shaft on top of the Expander Body.

Underpinning

Pushing. Unlike most other piling methods, the Soilex Pile can be pushed down to required depth with a relatively little effort using a hydraulic jack, as shown in the previous figure. The existing building is used to counter the pushing force. Compared to impact driving, pushing allows for longer pile elements, thus reducing the number of splices. If a new ground slab is made in connection to the underpinning works it is possible to prepare for the pile installation by concreting threaded nuts in the slab to which the jack is later attached.

Impact driving. The most common means of installation in narrow spaces is impact driving using a small drill rig adapted for low head room.

GROUTING OF THE SOILEX PILE

The pile shaft and the Expander Body are injected with cement grout, inflating the Expander Body. The grout pressure and volume are logged and stored using adapted monitoring equipment. The information is displayed during grouting as a chart on a laptop. The Expander Body diameter is evaluated from the logged information and can be compared with calibration charts. It is possible to double-check the injection data by measuring the shortening of the Expander Body.

The expansion process increases the density of granular soil. In cohesive soils, re-compression results in a pre-consolidation effect and improves soil strength and stiffness.

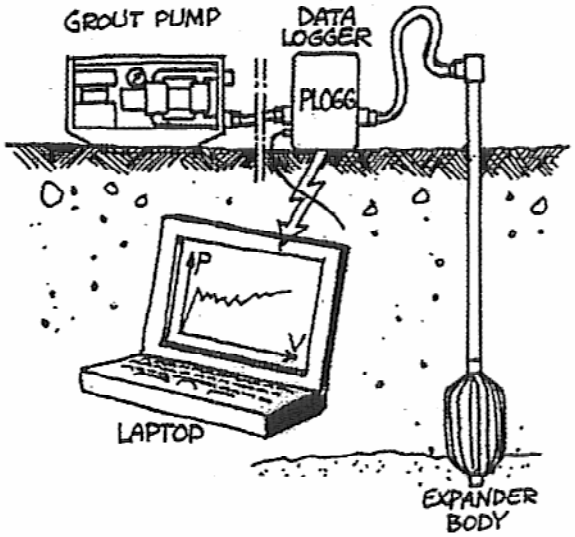

Figure 6. Data logging during inflation of the Expander Body

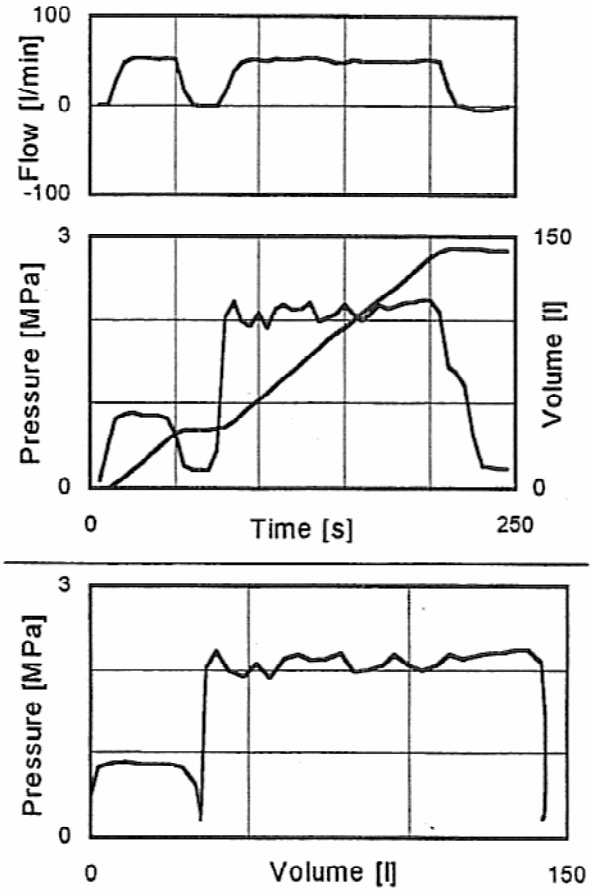

Figure 7. Expander Body grouting data

PRE-LOADING AND TESTING

In order to achieve contact between Expander Body and bearing soil layer the Soilex Piles can be pre-loaded during construction. The pre-loading is performed when the concrete has hardened in the inflated Expander Body. Methods have been developed to achieve a quick pre-loading and testing so that all of the installed piles can be tested and therefore making it possible to lower the factor of safety in certain cases.

When the pre-loading is performed using a drop hammer, conventional dynamic testing, up to about 2000 kN, is performed at the final impact. The gauges required for this measurement are mounted on a follower as shown on Fig. 8, which together with the drop hammer, can be rapidly moved from pile to pile, allowing 30 - 40 piles to be tested each day. The drop hammer weighs around 1.5 tons, depending on the total pile weight.

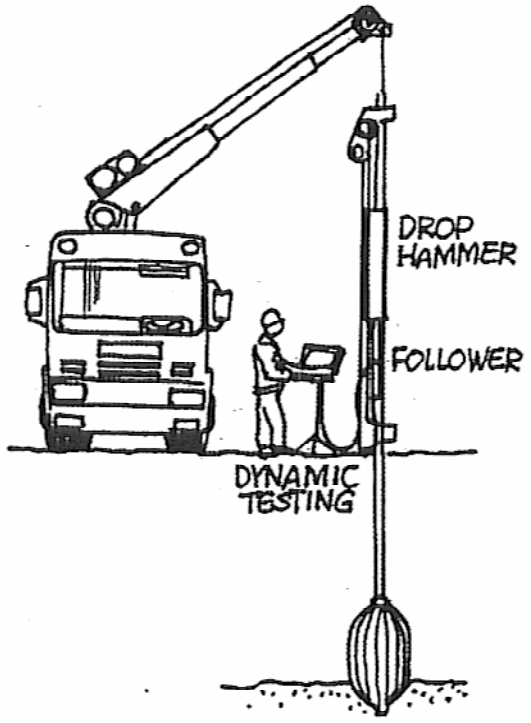

Figure 8. Pre-loading and testing using a drop hammer

In underpinning of an existing building, built-in jacks are used during construction to eliminate settlements in the pile shaft and below the Expander Body, Fig. 9. All Soilex Piles are test loaded and locked-off at the desired load.

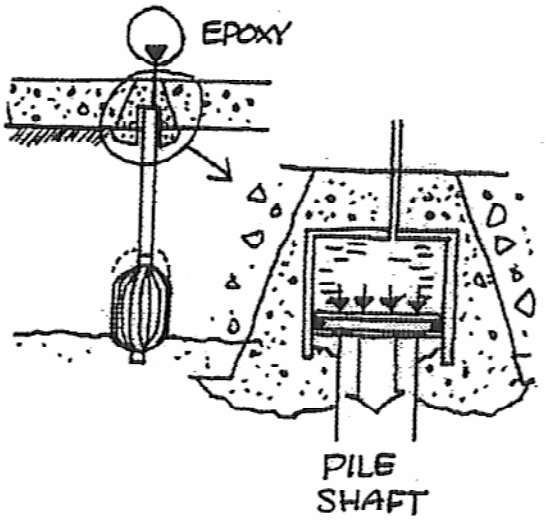

Figure 9. Pre-loading and testing using a built-in jack

CASE HISTORIES

Soilex Piles were installed by vibratory driving for the first time in 1993 near existing buildings founded on pre-cast concrete piles in silty sand susceptible to settlement due to ground vibration. The soil consisted of a fill over clay with layers of peat down to 4 m overlying dense silty sand. A steel pipe drifter was vibrated down and up in all pile locations to facilitate the pile installation. The 27 piles, with a working load of 650 kN, were vibrated into the pre-punched holes down to 7 m depth in only 4.5 hours. Soilex Piles were an economic alternative to impact driven pre-cast concrete piles, which would have required 38 piles to 18 m depth.

A new railway bridge at lake Mälaren in Sweden is another example where Soilex Piles were chosen as alternative to concrete piles. The piers and abutments were constructed only 2 – 10 m away from an existing bridge on an esker, typically consisting of poorly graded sand and gravel, extremely susceptible to settlement. Impact driving of concrete piles nearby caused settlements of up to 170 mm within the piling area. The client decided therefore to use Soilex Piles. Most of the 57 piles, with a working load of around 600 kN, were installed from a

pontoon. The horizontal distance between Expander Bodies at the foundation level should be greater than 3 diameters of the fully expanded base. This requirement was met by using inclined piles at two foundation levels. Uncertainties regarding remains from existing wood piling called for installation with casing. A casing with a lost tip was vibrated to target depth, about 12 m, in only 1 minute. The Soilex Pile was lowered with a wire into the casing, which was then extracted with the vibrator. About a week after grouting, dynamic testing with CAPWAP analysis was performed on 50 % of the piles.

CONCLUSIONS

New innovations lead to several advantages of Soilex Piles:

- Shorter piles – faster installation
- Less disturbance
- Preloading during construction
- Reduced future settlements
- Lower total cost