RETROFIT MINIPILE SYSTEM TO INCREASE THE CAPACITY OF EXISTING FOUNDATIONS

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SUMMARY: This paper describes a novel underpinning system incorporating Ankerbond and high capacity vertical piles bored through existing concrete foundations. A special cutting head, with three diamond tipped cutters, is used to cut three grooves in the cored holes through the existing concrete foundations. These grooves provide a strong pile head connection to transfer additional load from the existing foundations into the new piles, i.e. the existing foundations are upgraded. The advantages of this system are its ease of installation, its reduced construction time, and its efficiency due to the new vertical piles located closely around the existing columns. The result is that no foundation beams are required and that overall costs are significantly lower than other underpinning solutions. Two case histories are presented which involve the use of the Ankerbond system in conjunction with high capacity retrofitted minipiles. In these case histories, the capacities of the existing foundations were increased to accommodate an additional four storeys on top of existing buildings. Pile compression and tension tests are presented which validate this novel underpinning system and demonstrate its advantages for supporting increased foundation loads.
Keywords: Ankerbond, foundations, minipiles, retrofit, RuFUS, re-use, upgrade

Fig. 1: *The Ankerbond tool*

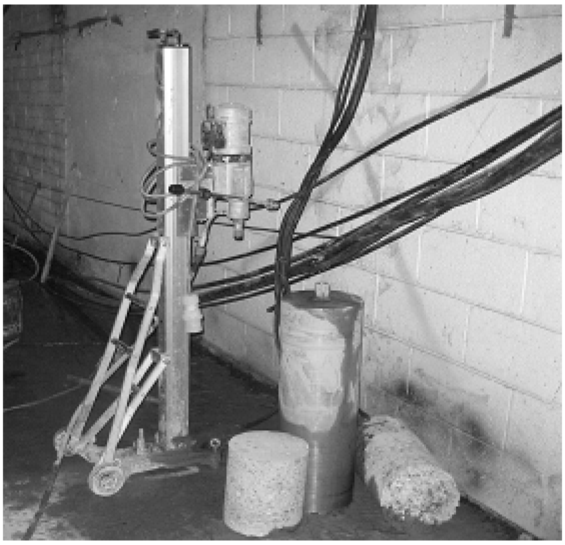


Fig. 2: *Coring rig and cores*

INTRODUCTION

When planning urban developments, the cost of demolition and the environmental and sustainability regulations affecting the disposal of construction waste are encouraging the re-use and upgrading of existing properties. When such developments involve adding floors or additional loadings to a building, then the existing foundations may need strengthening. A number of underpinning systems are available, but many involve inclined piles with reinforcement incorporated into new beams connected to the existing foundations to ensure an adequate transfer of load from the existing foundation to the new underpinning system. The Ankerbond system described in this paper avoids the need for foundation beams and hence the costs involved are significantly lower than in the case of other underpinning solutions

ANKERBOND SYSTEM

The Ankerbond system was designed by Holemaster Limited as a means of enhancing the pull out capacity of anchor bolts in concrete. This is necessary because high-speed rotary-cored holes through reinforced concrete can often have very smooth bores, which are difficult to 'roughen'. Therefore, unless there are long bond lengths, there is a risk of low grout to concrete bond values and subsequently low pull out forces for the anchor bolts. The system had previously been used on core hole diameters of up to 100 mm, however, Holemaster were willing to modify the system for use in 250 mm core holes through existing ground bearing bases and piles caps. This was initially undertaken at Colmstock House, Dublin, and then again at Leigh Mills Car Park in Coventry. The original scheme at Colmstock House required many retrofitted minipiles, inclined in several directions, in an attempt to overcome the issue of the minipiles punching through the smooth cored holes. With the Ankerbond system, it was possible to halve the number of minipiles by incorporating efficient vertical high-capacity minipiles within the existing pile caps. The additional loadings could then pass down the columns, into the

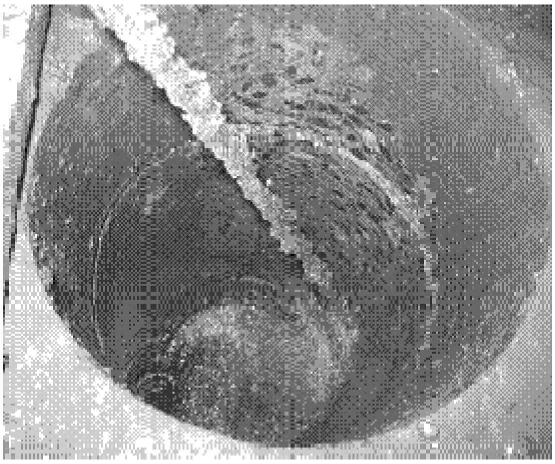


Fig. 3: *Cleaning Ankerbond & core hole*

Fig. 4: *Minipile ready for final topping up*

pile cap and safely into the minipiles via the Ankerbond system, which would then transfer the new loads deep into the underlying bedrock.

The first stage of the process is to form a 250 mm diameter vertical core through the existing pile cap or ground bearing base, a minimum 500 mm thickness of high strength concrete is required (>30 MPa). The modified Ankerbond tool incorporating three diamond tipped cutters (see Fig. 1), is then lowered mid-way through the base to form the three Ankerbond grooves and to try to roughen the remainder of the bore. The same drill rig does the initial coring and the Ankerbond grooves (see Fig. 2).

Following coring, forming of the Ankerbond grooves and roughening, the bore is cleaned with water (see Fig. 3). The minipiles are then constructed using 220 mm diameter temporary drill casing installed through the 250 mm diameter core holes and bored using 190 mm diameter augers or a 190 mm diameter down the hole hammer bit. The temporary drill casing is extended through unstable strata until open hole boring is possible. Upon reaching the required depth, the central reinforcement is placed and the minipile is fully grouted using a 1:1 sand cement (OPC Grade 42.5 N) grout mix with a 0.45 water cement ratio. Finally, the temporary casing is removed, whilst keeping the bore fully topped up with clean grout. After removal of the last section, a check is made that the Ankerbond grooves are clean and full of fluid grout, prior to final topping up (see Fig. 4.)

Two pull out tests were undertaken to test the effectiveness of the Ankerbond grooves. These comprised of 1.0 m lengths of 63 mm diameter GEWI reinforcing bar cast into the existing ground bearing pads. The two tests were taken up to 1.5 x design load or SWL (safe working load) of 1,075 kN = 1,612 kN, which is comfortably below the reinforcing bar yield strength of 1,758kN. Care was taken to ensure that the reaction beams did not exert pressure within 0.5 m of the reinforcing bar, to prevent any strut effect. Both tests performed well and safely held the maximum test load, showing elastic movement of ~5 mm, which is explained by the elastic extension of the free length of reinforcing bar through the test jack (see Fig. 5).

THEORETICAL BASIS FOR SYSTEM AND DESIGN ASPECTS

The design of the minipiles connected to an existing pad foundation or pile cap using the Ankerbond system involves checking all the possible modes of failure when the

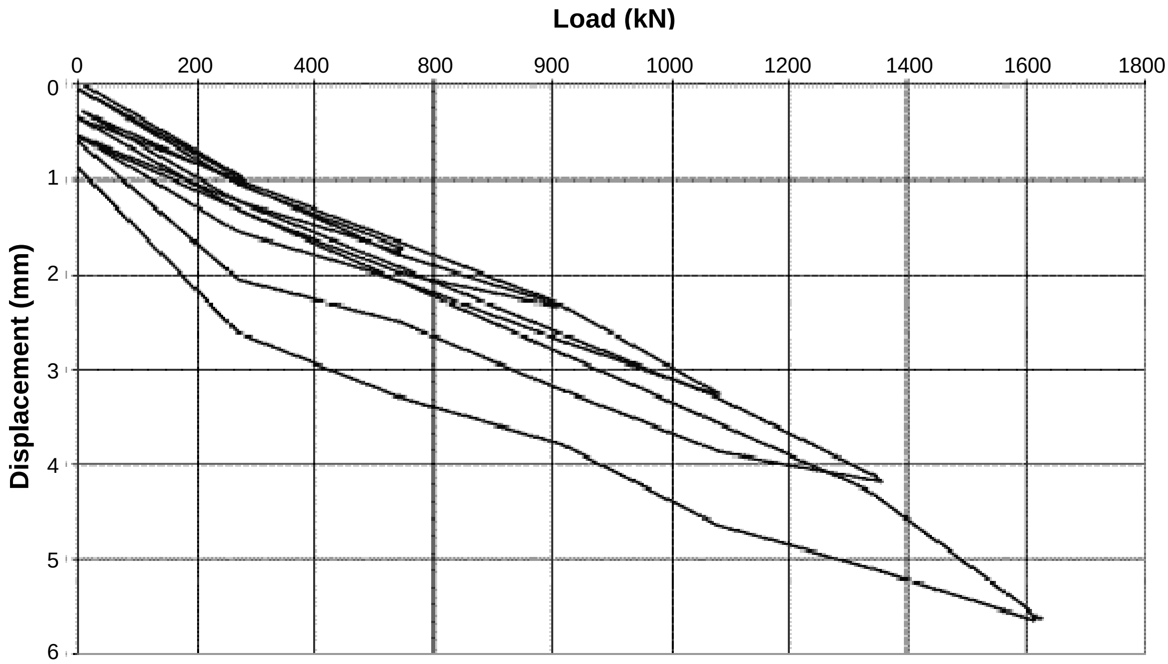


Fig. 5: *Ankerbond Pull Out Test No 2, Colmstock House, Dublin*

minipiles are subjected to additional loading applied to the structure. These modes of failure include:

- shear failure between the minipiles and the existing foundation
- bearing failure of the minipiles in the underlying bedrock, and
- settlement of the foundation with the new minipiles.

The resistance against shear failure between the minipiles and the existing foundation may be analysed for the critical failure mechanism which consists of shearing along the roughened cylindrical vertical core hole surface in the existing concrete foundation and through the three concrete nibs projecting into the Ankerbond grooves formed in the core hole shown in Fig. 3. The depth of the roughened core hole is 300 mm, the depth of each Ankerbond nib is 22 mm and there are 3 nibs. If the concrete has a characteristic compressive strength of 40 MPa, then according to BS 8110, the design shear strength for shearing between the roughened zone and the minipile is 40/10 = 4 MPa. and for shearing through the concrete nibs is 5 MPa. Hence, for a core hole diameter of 250 mm, the resistance against shear failure between a minipile and the existing foundation is:

$$(\pi \times 250 \times 300 \times 4 \;+\; \pi \times 250 \times 3 \times 22 \times 5) / 1000 \;=\; 942 + 259 \;=\; 1{,}201 \text{ kN}$$

The pull out tests described above, which were carried out to a maximum test load of 1,612 kN, confirmed that the Ankerbond system provided adequate resistance against shear failure between the minipiles and the existing foundation and demonstrated that the analytical model used above for the shear failure is conservative (See Fig. 5). In the case of the Ankerbond system, additional resistance against shear failure between the minipiles and the existing foundation is provided by the existing foundation restricting dilation and hence increase increasing the shearing resistance on the failure plane.

Fig. 6: *Colmstock House – front view*

Fig. 7: *Colmstock House – rear view*

The additional resistance against bearing failure in the underlying bedrock is determined by calculating the shaft resistance of the minipiles in the sockets bored in the bedrock; the end bearing resistance is ignored. Greater bearing resistances are provided by increasing the depth of the sockets in the bedrock, as explained below in the case of the Colmstock House foundations. The bearing resistance and the foundation settlement behaviour should be checked by carrying out pile load tests, as described in the case of the Leigh Mills Car Park.

CASE HISTORY 1 – COLMSTOCK HOUSE, DUBLIN

In late 2004, Bennett Construction Limited commenced the refurbishment of The Department of Justice, Colmstock House, 72 to 76 St Stephen's Green, Dublin 2, shown in Figs. 6 and 7. This prime real estate was to be upgraded as a high quality office development, which included the addition of an extra storey. O'Connor Sutton & Cronin (OCSC) had undertaken a preliminary assessment of the building structure and foundations and had determined that the existing columns and ground bearing concrete pads were unable to accommodate the additional loadings.

The site investigation works comprised two cable percussion boreholes to refusal in limestone bedrock at ~ 6.0 m depth and five trial pits to determine the size and depth of the existing pad foundations. The ground conditions were typical for central Dublin and comprised ~ 2 m of made ground over ~ 3 m of stiff to very stiff Dublin Boulder Clay over 1 m of dense gravel over strong limestone bedrock. The groundwater level was within the gravels at ~ 5 m depth. The existing pad foundations ranged from 500 mm to 700 mm deep and from 2.5 m to 4.0 m square, below a 200 mm thick basement car park slab. OCSC were concerned about the bearing capacity of the founding strata for the bearing pads and therefore specified substantial upgrading of the existing foundations with high capacity minipiles.

The original OCSC scheme, shown in Fig. 8, detailed ~ 400 nominal 150 mm diameter minipiles. These were a combination of vertical and inclined piles, some with head plates, to reduce the risk of punching shear failure with high capacity minipiles. Cementation Foundations Skanska Limited proposed an alternative scheme with 190 nominal 200 mm diameter vertical minipiles. This alternative scheme, shown in Fig. 8, incorporated Ankerbond grooves to provide a strong bond into the existing pads and remove the risk of punching shear failure. The additional loadings per base (i.e. minipile loadings) ranged from 249 kN to 4,194 kN. In order to achieve the optimum minipile numbers and layout a variety of minipiles with design bearing resistances of 400 kN, 700 kN, 900 kN and 1,075 kN were adopted. All of these minipiles were founded between 2.0 m and 4.0 m into the strong limestone bedrock (unconfined compressive strength (UCS) > 100 MPa), depending upon the required design bearing resistance. These minipiles are primarily shaft friction piles and a working grout to limestone bond value of 250 kPa was used over the top metre, which was increased to 500 kPa thereafter. End bearing components were ignored due to the small area and the risk of debris in the base.

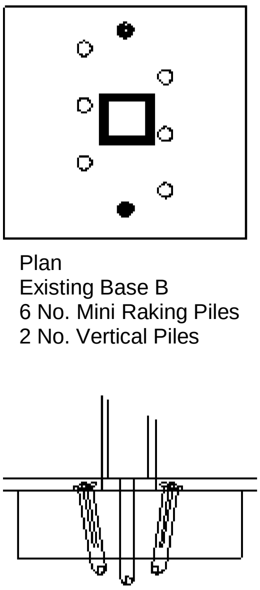


Fig. 7: O*riginal minipile layout*

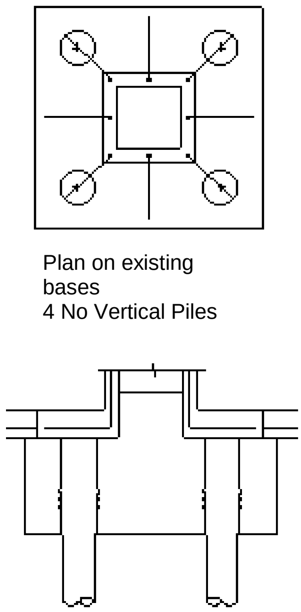


Fig. 8: *Optimised Ankerbond layout*

The minipiles were formed by installing temporary 220 mm diameter steel casings through the cored holes (with Ankerbond grooves) and sealing them into competent bedrock. Open-hole air-flushed down-the-hole hammer drilling techniques were then adopted to form the 190 mm diameter rock sockets. The bedrock proved extremely strong and consistent across the site at ~ 6.0m below the piling platform level (basement level), which resulted in minipile lengths between 8.0 m and 10.0 m. The minipiles were drilled within the low headroom basement car park using an electric Hutte 202 drill rig with a 2.2 m drill mast. Upon reaching the founding depth, a centralised reinforcing bar was inserted to the full depth in 2.0m lengths, connected together using full strength couplers. This reinforcement bar ranged from 25 mm to 63.5 mm diameter, depending upon the pile design bearing resistance.

Finally, a 1:1 colloidally mixed (high shear) sand:cement grout mix was pumped into the base of the bore via a small diameter tremie pipe until completely full of clean grout. The temporary casing was then removed, whilst keeping the bore continually topped up with grout. Upon completion, the Ankerbond grooves were checked to ensure they were clean and full of fluid grout. Average 28 day UCS grout cube results of > 50 MPa were achieved. The result of a static pile test conducted on a pile in the rear courtyard is given in Fig. 9. This show maximum movement of ~ 18mm at 1.5 SWL, which recovers to less than 8 mm at zero load. These are very large loads for a 220 / 190mm minipiles and the majority of this movement is elastic compression of the pile shaft. The dead load component elastic compression is taken up during the construction period. The existing columns were strengthened by casting 100 mm of reinforced concrete around every column; this also increased the efficiency of the force transfer mechanism into the minipiles. The works were completed on programme and on budget. A key element of the success of this project was the Ankerbond system, which helped to provide the client with an efficient and cost effective solution.

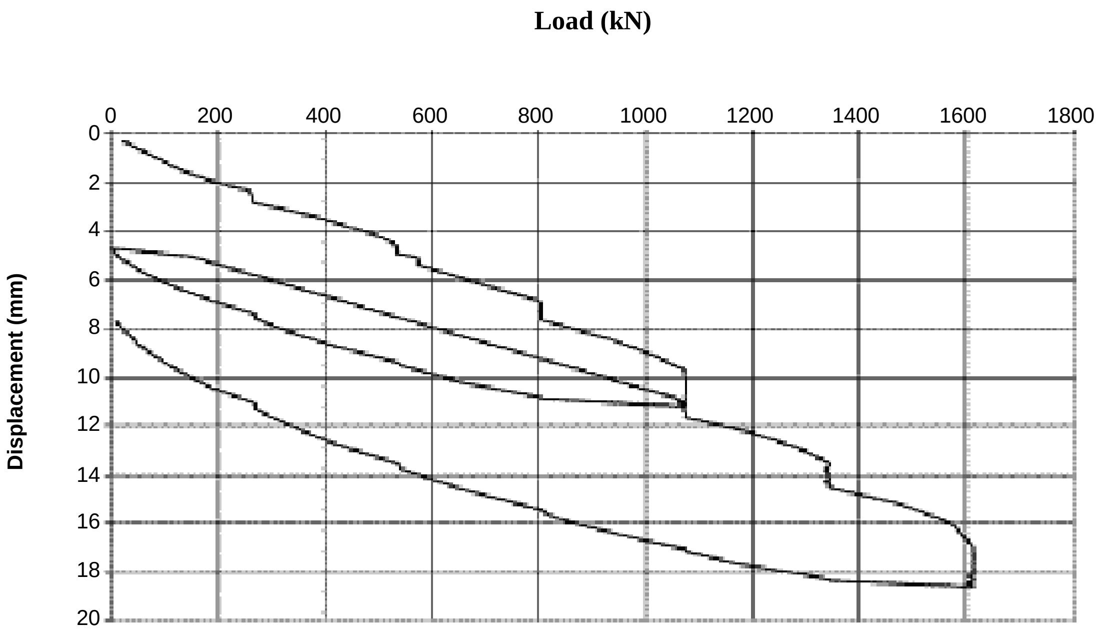


Fig. 9: – *Static load test*

CASE HISTORY 2 – LEIGH MILLS CAR PARK COVENTRY

Leigh Mills Car Park is quoted in the RuFUS Handbook[1] and in Tester et al.[2] as a classic re-use situation. It involved providing four floors of extra space above an existing car park. In re-use situations, it is seldom that the additional load is coincident with the existing columns that can carry extra load and that existing foundations require minimal strengthening, however, this was the case at the Leigh Mills Car Park.

The car park details are shown schematically in Fig. 10. The original foundations constructed in 1989 generally comprised pile caps with short continuous flight auger (CFA) piles founded approximately 1.5m into the weathered Coventry Sandstone. In 1989, CFA piling rigs operated at relatively low torques of < 5 tonne metres (tm), compared with today's 25+ tm piling rigs, and forming CFA rock sockets could be difficult. Therefore, a conservative 600 mm diameter pile was adopted to ensure buildability and structural integrity. This resulted in piles with higher load carrying capacities than was required for the four-storey car park. The original pile design bearing resistance was 650 kN, whereas in fact the actual bearing resistance was probably 100% greater.

The tender enquiry for the extension works envisaged piercing existing slabs, adding supplementary columns, founding the columns on new caps supported by 1,000 kN bearing resistance minipiles and then raising the car park by a further four storeys. The disruption and difficulty of such a proposal is apparent and is exacerbated by the need to work in limited headroom. The ability to re-use the existing columns and piles led to the adoption of the more efficient sustainable solution (1, 2), with associated cost and programme savings, which is consistent with the objectives of the EU funded project RuFUS for the re-use of foundations for urban sites. These savings would have been significant even if supplementary pile caps had been necessary. The columns to the existing car park were able to withstand the additional loadings without strengthening due to redundancy in the original design. The elegance of the adopted scheme is that by

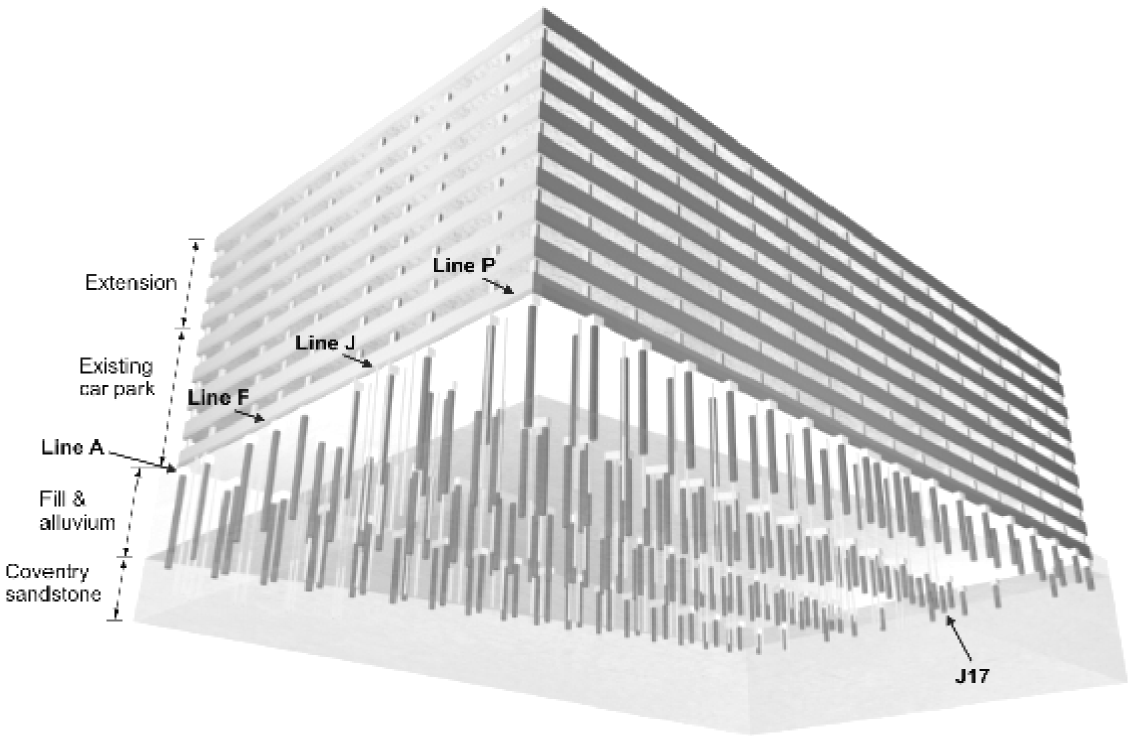


Fig. 10: *Schematic view of foundations and ground conditions for Leigh Mills car park*

using the Ankerbond technique it was possible to avoid additional local pile caps, for approximately 60% of the foundations, i.e. essentially the 3-pile groups shown in Fig. 11, and restrict the number of interconnecting double pile caps illustrated in Fig. 12.

This paper addresses the performance of the caps that employ the Ankerbond process. As illustrated in Fig. 13, the Ankerbond system comprises a roughened length and a keyed bond length within the pile cap. For the system to transfer the additional loading to the minipile, the concrete host cap must have sufficient strength (> 40 MPa for a 500 mm deep cap) to ensure structural integrity and sufficient depth to allow full bond development and load transfer. The whole system (piles, cap and ground) must be of compatible stiffness to other pile groups to ensure that differential movement across the structure is negligible. The design of the supplementary minipiles to the 2 and 3 piled cap foundations requires consideration of relative pile movement as well as ultimate load; indeed this is often the prime consideration in a re-use situation.

Interestingly, the large difference in stiffness between 600 mm diameter piles and 200 mm diameter minipiles may mean that the latter are 'comfort' providers rather than full load-sharing elements. However, the minipiles are intimately bonded provisions into the pile cap and generate their axial capacity quickly because they are primarily shaft friction piles, i.e. they develop their capacity within 2 to 4 mm of movement (equivalent to 1 to 2% of the shaft diameter).

As part of the design validation process for the Leigh Mills Car Park, it was determined that the depth of the existing pile caps was > 750 mm. The consulting engineer confirmed that the pile cap concrete strength was > 40 MPa and the cores in the existing piles showed average pile cube strengths of 53 MPa. To further assess performance and design predictions, extensometers were placed in three piles to monitor compression as the additional four storeys were constructed. Precise levelling of selected

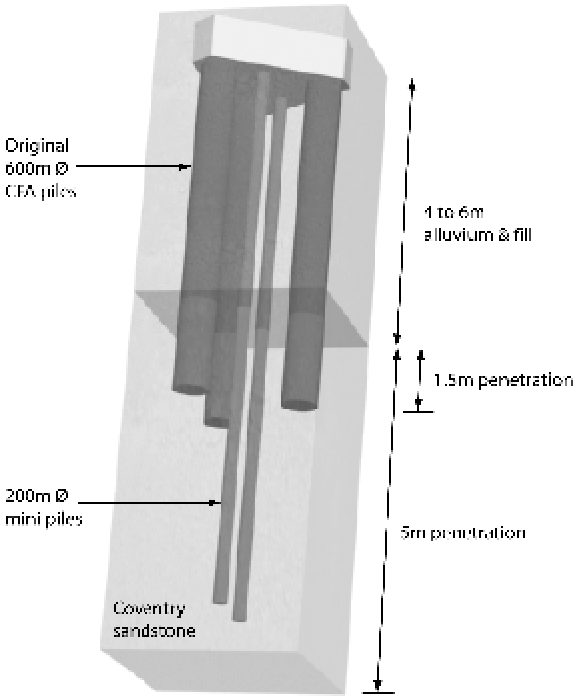


Fig. 11: *Isometric view of 3 cap group supplemented by mini piles (utilising Ankerbond)*

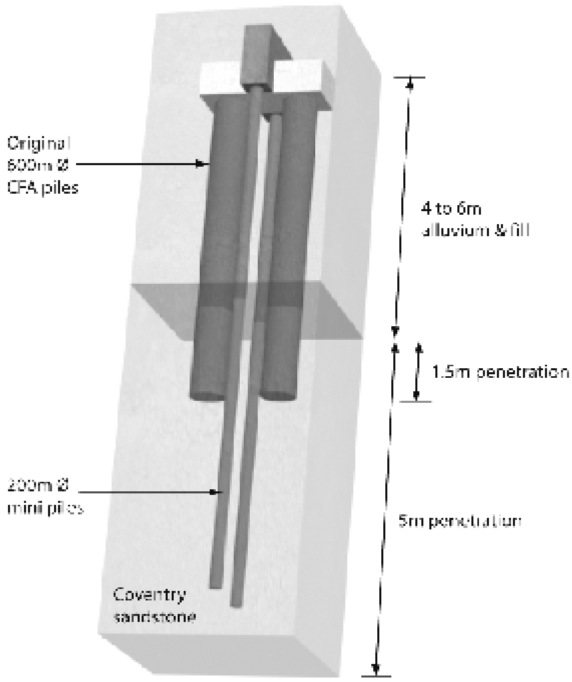


Fig. 12: *Isometric view of 2 cap group supplemented by mini piles & further pile caps*

foundations (referenced to a unique deep levelling point) was carried out to note strain effects across the building as the loading built up. The Building Research Establishment (BRE) carried out this work independently; some results are given in Fig. 14, for strike line J noted in Fig. 10.

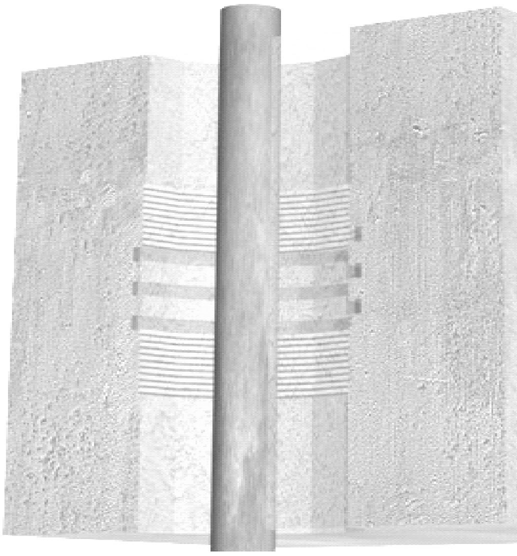


Fig. 13: *The patented Ankerbond system*

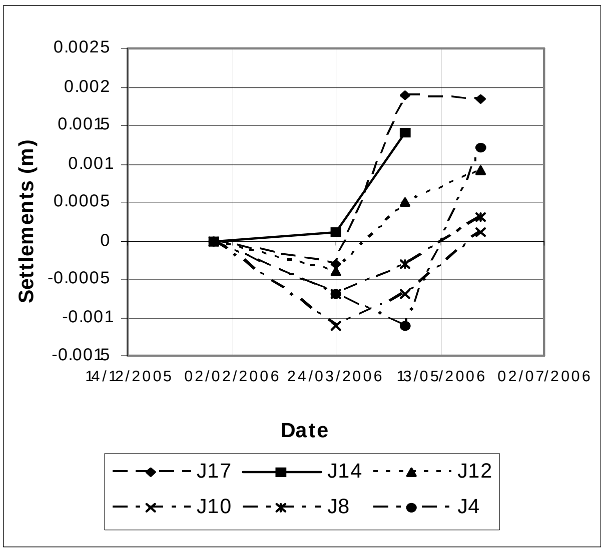
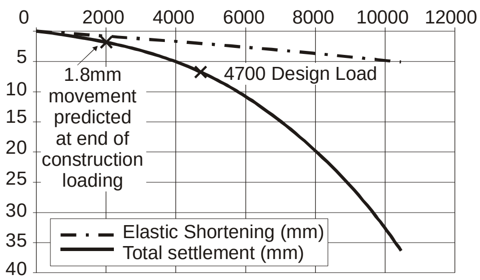


Fig. 14: *Typical recorded settlements from levelling surveys*

The settlements recorded from the pile load tests carried out between January and June 2006 are shown in Fig. 15. These pile load test results allowed a Fleming[3] Cemset group analysis to be carried out for a pile group foundation consisting of 3 CFA piles



Input data

Pile shaft diameter	1070mm
Pile base diameter	1070mm
Shaft free length	4.5m
Shaft friction length	2.5m
Ultimate shaft friction	4241kN
Ultimate end bearing	15268kN
Concrete modulus	1.50E+07 kN/m^2
Soil elastic modulus at base	200000 kN/m^2
Shaft flexibility factor Ms	0.0015
Friction centroid Ke	0.4
Load increment	500 kN
Working load (optional)	4700 kN

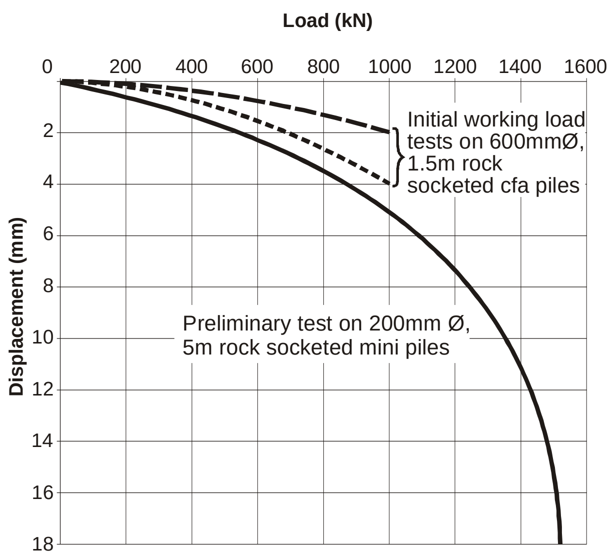


Fig. 15: *Cemset group analysis*

Fig. 16: *Load settlement graph*

and 2 minipiles, with the group modelled as an equivalent 1,070mm diameter pile. The results of this analysis, plotted in Fig. 15, suggest that for a design load of 4,700 kN the 'Ankerbonder group' would settle in the region of 7mm, dependent upon the pile length and local variations. The maximum-recorded settlement on completion of construction was about 2 mm at foundation group J17. If it is assumed that 60% of the design load of 4,700 kN is dead load with a load factor of 1.48, the actual force exerted on the pile cap at the end of the construction loading will be:

$$4{,}700 \text{ kN} \times 0.6 / 1.48 = 1{,}905 \text{ kN}$$

i.e. close to the Cemset pile group prediction of 1.8 mm at 2,000 kN shown in Fig. 16.

Alternatively, the recorded settlement behaviour of the pile group may simply be the reloading of the 600 mm diameter piles along the 'reload' line up to 2,000 kN. In truth, the settlement monitoring has revealed such small values that conclusions are more grounded in speculation than reliable interpretation. The foundation caps appear to have settled about 1 mm, with a maximum settlement of 2 mm, indicating an angular distortion of about 1 in 5,000, i.e. negligible. Whilst the overall settlement may increase with time, the rotational movement should never be a problem. Perpendicular cross-sections reveal a consistent settlement pattern throughout the building. None of this is surprising given the degree of redundancy introduced in re-use situations and the strength of the founding sandstone bedrock.

In total, approximately 200 nominal 200 mm diameter minipiles were installed, founded 5 m into weathered sandstone bedrock. All minipiles were reinforced to the full depth with a central 50 mm diameter reinforcement bar, connected together in short lengths using full strength couplers. A 1:1 sand cement colloidal (high shear) grout mix with a 0.45 water cement ratio was tremie grouted into the base of every pile until completely full of clean grout. It was possible to auger drill the weathered sandstone bedrock to form the 5.0 m rock socket as shown in Fig. 17.

Cementation Foundations Skanska Ltd. were the original piling contractor and were able to locate all of the original construction and testing records. Cementation were then successful in winning these low headroom minipiling works and were able to re-warrant all of the piles beneath the new structure for a further 15 years.

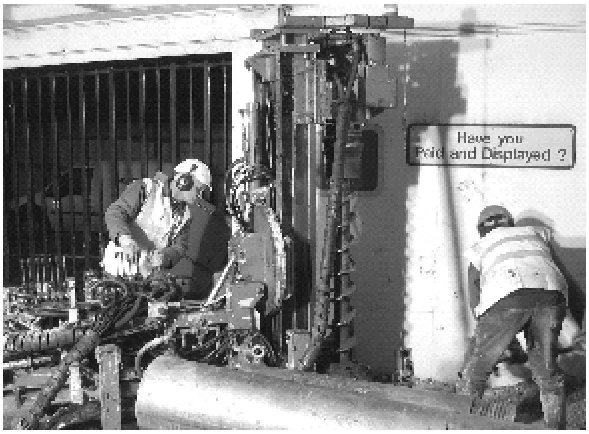


Fig. 17: *Auger drilling miniplies*

In summary, circumstances permitted the efficient upgrading of the existing piles and foundation caps for the upward extension of the Leigh Mills Car Park. High capacity minipiles installed in low headroom were able to upgrade the load bearing capacity of the existing foundations. The Ankerbond system allowed minipiles to be added to approximately 60% of the existing pile caps, thereby reducing the need for costly pile cap enlargement.

CONCLUSIONS

This paper describes the novel Ankerbond minipile system, which consists of installing high capacity vertical minipiles through existing foundations in order to increase the bearing capacity of existing foundations. This is achieved by coring through existing pile caps or spread foundations and then extending the minipiles deep into competent underlying strata. A key feature of the Ankerbond system are the three grooves cut in the existing foundation and the roughened zone by which the additional loading is transferred into the 'new' foundations. The advantages of the Ankerbond system are that, as the minipiles are vertical, they can be installed in foundations close to the columns carrying the additional loading and fewer minipiles are required than in existing systems. Also, since the minipiles are vertical and no raking piles are required, the installation is simpler and they can be installed when working in confined spaces. Thus the system is both efficient and economical. The design of the Ankerbond system has been justified by checking the safety of the minipiles against both shear failure between the minipiles and the existing foundations and bearing failure in the underlying founding strata. These checks have involved design calculations, static pull-out tests and static pile loading tests. Two case history examples are discussed, one for an office block in Dublin and the other for a car park in Coventry. Both of these case histories involved the installation of Ankerbond minipiles to increase the bearing resistance or capacity of the existing foundations to sustain extra loading due to additional floors. The successful performance of the minipiles in these two case histories, with minimal settlement recorded in either case, demonstrates the suitability and effectiveness of the Ankerbond minipile system for the upgrading of existing foundations.

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