Deep Resonant Micro Piling for Netherlands Grade Separation

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Abstract:

The Resonator RD 260 Resonant Pile Driver delivers ground disturbance free, high production micro pile installation. The Resonator was recently used at the site of a major grade separation south of Amsterdam, at Den Haag, to install 34 m long micro piles. The micro piles are used as both compression and tension elements for the support of the structure walls and roof and to hold down the roadway base due to hydraulic uplift forces.

A test program involving several installation methods proved the Resonant driver would install the 168 mm dia 34 m length test pile to full depth in just 11 to 15 minutes. The Resonator was crane mounted and drove a single length 34 m tube through mixed sands and silts with CPT Qc of over 300 Bar. The single pass pipe was installed with a loss bit and no flushing. Thus, the micro pile was installed with zero ground vibration, no spoil and no flushing fluids to contend with. Competing methods included sonic drilling (which could only penetrate to 19 m depth) and conventional water flush drilling which took over 90 minutes to reach a depth of 28 m.

The micro piles were pressure grouted during casing removal at intervals of 3 m and at grout pressures of 20 Bar. Load testing confirmed the micro pile capacity to be 1125 kN to 2160 kN, depending upon the grouting procedures.

Rotterdamsebaan Tunnel Grade Separation Project

The city of Den Haag is constructing an underground thoroughfare between the perimeter highway system and the downtown core. The project is called the Rotterdamsebaan and features the "Victory Boogie-Woogie Twin Tunnels". The construction involves extensive connection road reconstruction, tunnel approaches and a section of twin tunnels.

Figure 1. The future South Tunnel Approach at the Rotterdamsebaan

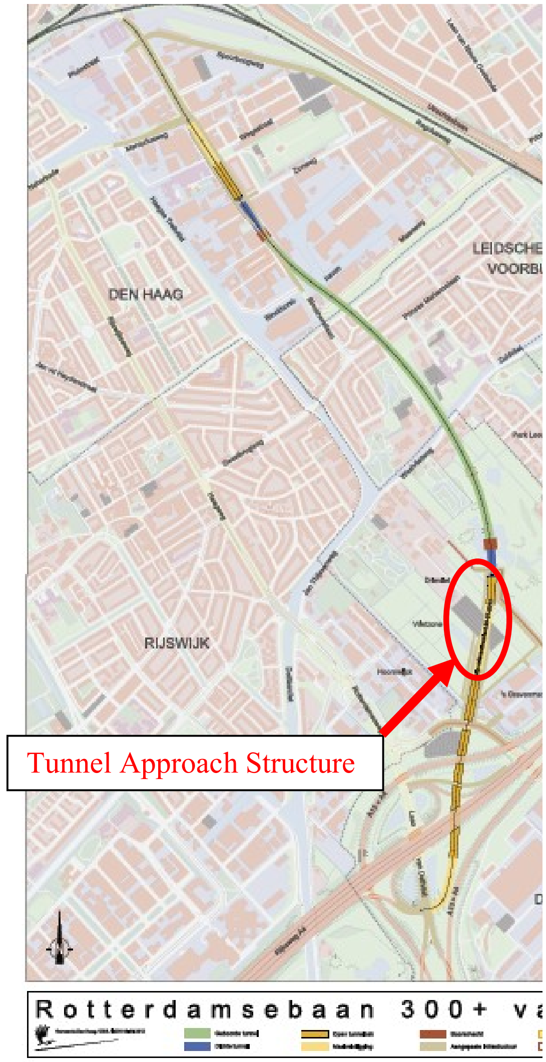

Figure 2. Rotterdamsebaan Site plan.

The tunnel approaches are being constructed to depths of 8-10 m within water bearing sands and silts. The alluvial formation remains compact to dense to depths of over 50 m. The tunnel approaches will be constructed in the wet with steel sheet piling cofferdams at the approach and exit shafts. The base of the cofferdams will be susceptible to hydrostatic upheave forces and piping due to the high water table and weak soils.

A tremmied base slab will be used to support and hold down the road surface. The tremmie base slab will consist of a 1-1.3 m thick reinforced concrete slab integrated with 26 m long tension micropiles. The micropiles are to be constructed from existing grade to depths of 34 m. The micropiles are constructed using high tension reinforcing bars and high strength grout placed in 'Resonated' holes or conventional drilled holes.

A test program was conducted to verify both installation method and micropile tension capacity. 6 months prior to construction a test program was conducted using 3 methods to construct the micropiles followed by tension load tests.

How Does Resonance Work?

The Resonant Pile Driving method is gaining acceptance around the world as a new method to rapidly drive piles free of ground borne vibrations. The high frequency vibrator resonates the pile, essentially turning the pile into a spring, to excite the toe of the pile with high accelerations and low amplitude. High acceleration with low amplitude generates high penetration rates, but the high frequency stress waves are quickly dissipated in the soil. Typically Resonator ground borne vibrations are measured at below 1 mm/sec within 1 to 5 m of the pile. The Resonant method can drive a pile next to a glass of wine, without causing ripples, as has been demonstrated on numerous piling sites.

The Resonant method uses a hydraulic piston - cylinder geometry to generate high magnitude, high frequency oscillating forces. This is a very different mechanism than the eccentric mass technology used in conventional and variable moment vibrators.

A unique valve geometry achieves the high frequency flow switching necessary to oscillate the hydraulic piston at up to 180 Hz (10800 VPM). The valve is controlled electronically for maximum accuracy of the desired frequency using an in dependent hydraulic circuit. The separate, main hydraulic circuit controls force and amplitude. The volume of hydraulic oil delivered to the piston (flow rate) determines the vibration amplitude while the hydraulic pressure determines the peak force.

The main advantage of the Resonant piston-cylinder method is that it allows the vibration frequency to be tuned to the natural frequency of the pile, which excites the pile like a spring. Exciting the pile like an axial spring allows the storage (build up) and release of vast amounts of energy. In this way the pile is brought to a high acceleration state that penetrates through the soil quickly. The challenge is to continuously tune the vibration frequency to the natural frequency of the pile and soil as it is advances into the ground. A computer algorithm has been developed for the Resonant Driver which automatically performs this tuning function. Through tuning to the Resonant frequency of the pile the maximum driving efficiency and maximum force at the pile tip is achieved.

Test Program and Tension Load Test Results

BAM Contractors NV was awarded the foundation aspects of the project as part of a joint venture contract. The contractor undertook an extensive test program to prove the construction methodology, productions and anchor capacity. The test program was conducted as a separate contract 6 months prior to commencement of the project.

Three methods of micropile construction were used for the test program: conventional drilling double rotary top rotary drives and water flushing, the sonic drill method and Resonant pile driving. Conventional rotary drilling using a casing and drill string with separate top drive (with reverse rotation) and water flushing was used. The 163 mm dia segmental casings were advanced to a depth of 28 m and a 63 mm dia high strength bar inserted. Grout was tremmied into the hole with incremental pressure grouting to 20 Bar conducted as each 1.5 m section of drill string was removed. Grout volumes were monitored during each test pile to ensure consistency between micropiles and prevent a false test result due to over grouting.

The second micropile construction method used the Mid-sonic drill mounted on a 163 mm dia drill casing made up of two sections: the first 19 m long and the second 15 m long. The casing was advanced using a loss bit with no flush. The sonic method vibrates the pipe axially at very high frequency (150Hz or 9000 VPM) in order to advance the tip. The BAM had used this method successfully on a previous anchor program and achieved very high productions for anchors driven to a depth of 22 m. However, at this site a dense layer at a depth of 16 m proved to be too tough for the sonic drill heads. The sonic drill heads were the Midsonic SonicSamp product by Eijkelkamp (NL). The midsonic drill advanced the 19 m casing to a depth of about 17.5 m and could not advance it further or remove the casing.

The third micropile construction method used the Resonator pile driver on the same 19 m and 15 m long casings. In this case the Resonator was used to remove the 19 m stuck casing from the sonic drill test. The casing was driven to 19 m depth and the 15 m section added. The casing was driven with the loss bit in place and no flushing to the target depth of 28 m where soils with Qc on the order of 30+ MPa were encountered. The casing was driven with the Resonant driver in only 14 minutes, so an attempt was made to drive the casing to the full length of 34 m. The casing was driven to full depth in another 3 to 4 minutes. Despite the ease of achieving additional micropile length, all test anchors were installed to a 28 m depth.

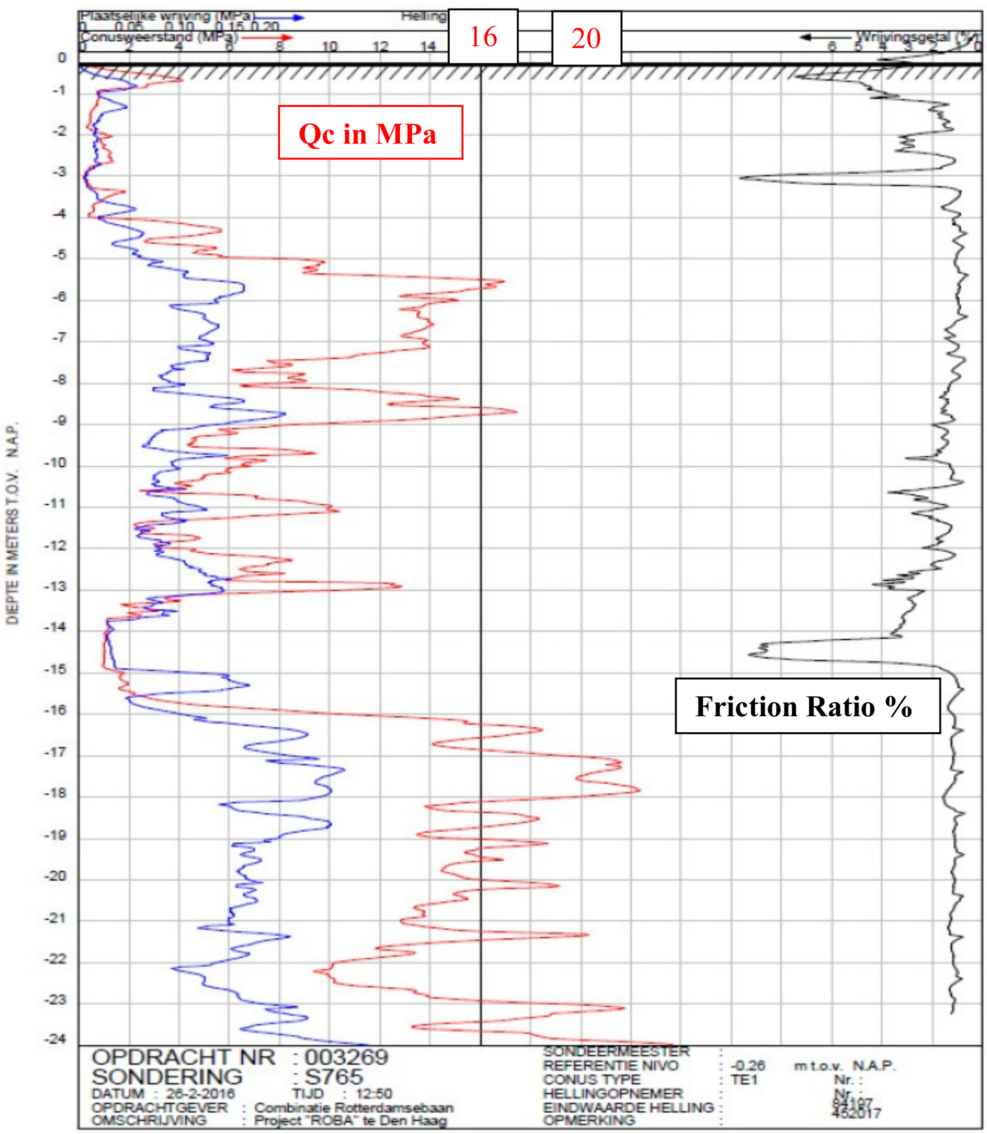

Figure 3a. Typical CPT at Rotterdamsebaan site, Den Haag, page 1.

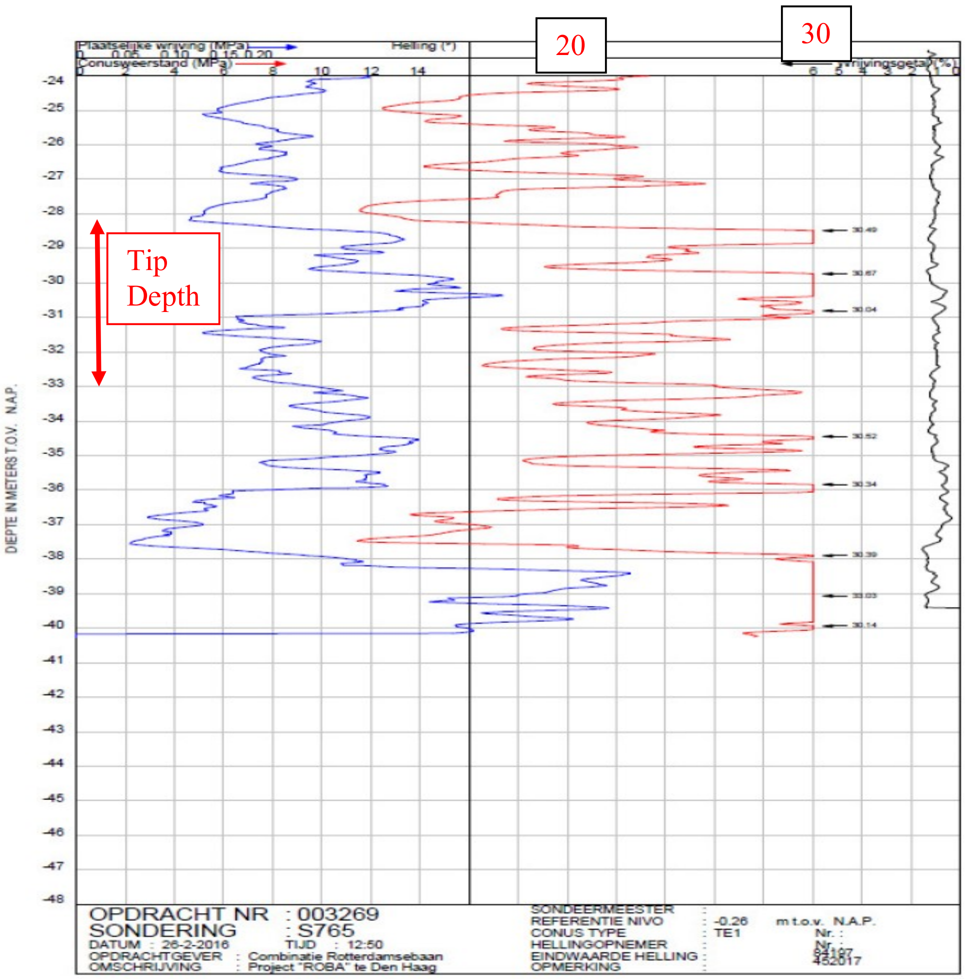

Figure 3b. Typical CPT at Rotterdamsebaan site, Den Haag, page 2.

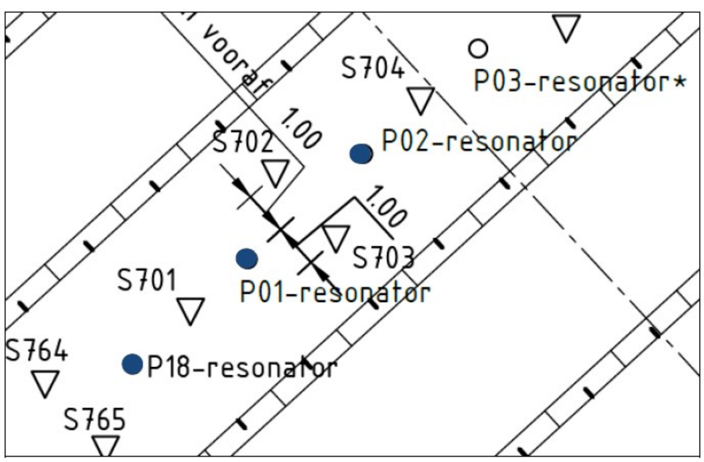

Figure 4 South approach site plan showing Resonator Test Anchors

The loss bit was fitted with an O-ring seal to prevent groundwater from entering the casing during driving. As a result the bar could be inserted into the casing in the dry and grout placed into the casing without the need for a tremmie, which improved production. The grout line was connected to the top of the casing and the Resonator clamp was fabricated with a seal to permit constant pressure grouting to 20 Bar during casing extraction.

The test program was continued using the conventional drill method and Resonator driver for over 30 anchors to explore alternative methods and establish optimum production. On several occasions grout takes were deemed too large and the anchors abandoned. In the end a selection of 6 anchors were tension load tested.

Anchor testing was conducted on selected, representative anchors. Selection was based upon optimum production methods and what were deemed to be representative grout takes for both initial grouting and during pressure grouting. Despite the care taken during installation tension load test capacity varied greatly between micropiles.

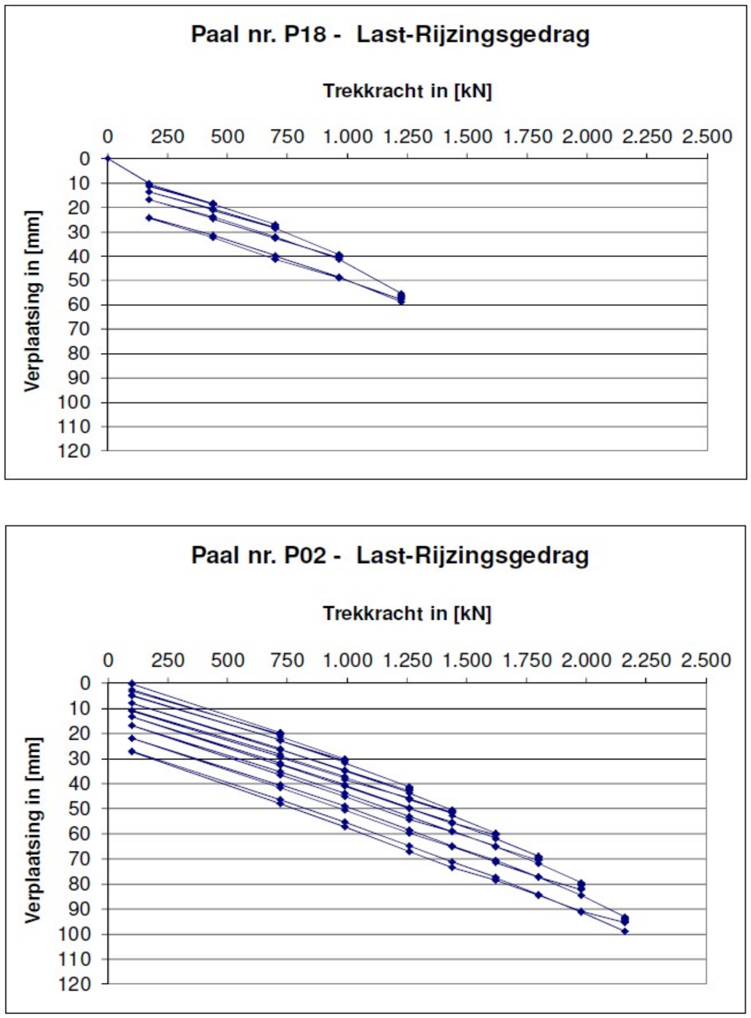

Figure 5 Test Anchor load results

Three Resonator installed micropiles were tested with anchor bond zones of 6.5 m, 7.5 m and 8.5 m for piles P01, P02 and P18 respectively. All anchor bond zones were developed to 28 m tip elevation. Thus the anchor zones started at 21.5 m, 20.5 m and 19.5 m respectively. The load test results indicated peak loads for the Resonator driven micropiles varied between 1250 kN and 2200 kN (failure was by creep at 2 mm per log cycle). Pile P02, with the 7.5 m bond zone provided the highest capacity at 2200 kN, or 442 kPa bond stress while micropiles P01 and P18 provided 228 kPa and 238 kPa bond stress respectively. The wide range may have been due to variance in grout takes during pressure grouting. Micropile P02 took 200% of the pressure grout volume of micropiles P01 and P18. The P01 and P18 anchor capacities fell below the expected bond stress (approximately 300 kPa). Though the higher capacity bond stress was achieved with the higher grout takes under pressure grouting, it was not assumed that this could be achieved for all production micropiles. Thus, the lower grout takes and lower bond stress was assumed for design purposes.

Production Micropiles

A total of over 4000 tension micropiles were required for the two tunnel approaches to the Victory Boogie-Woogie Twin Tunnels. The micropiles were spaced at 1.8 to 2.4 m centre centre on a rectangular grid. Low cut offs, at between 2 and 9 m below grade, meant that bars were not proud of the working surface. However, micropile 'holes' were abundant and treacherous for equipment and workers. Given the large number of micropiles two spreads of equipment were commissioned for the project. A conventional drilling spread was used which included 2 Klemm drills, 2 support excavators outfitted with drill casing and drill string handling arms, an excavator for spoil removal, a 150 tonne service crane and a grout plant. The drills and accompanying equipment comprised a crew of 11, including a foreman. The crews worked an 11 hour day and produced up to 4 micropiles per drill per day.

Figure 6. The South Tunnel Approach during foundation construction

Figure 6 shows the conditions on site during micropile installation. The drills and service machines are seen in the foreground within the future cofferdam footprint. The 150 tonne crane handling the Resonator is located beyond the drills. The drilling area of the site proved problematic due to the introduction of copious amounts of water for drilling and casing cleaning. Spoil removal proved particularly problematic with large amounts of wet sands and grout to be handled on a crowded site with poor access.

For production work the Resonator was installed on a 40 m vertical lead mounted on a 150 tonne base crane. The Resonator power pack (400 Hp) was mounted on a frame attached to the back of the crane. The leader was mounted with a sliding casing gate to support the 163 mm dia, 34 m long casing at its midpoint and avoid buickling. The grouting system used a 32 mm dia grout line which doubled as a water line for washing down equipment and cleaning the connection between the Resonator and the casing. A permanent grout nipple was integrated into the top of the casing for introduction of pressurized grout during extraction. Figure 7 shows the Resonator with clamp and sealing spigot and the top of the casing. A large diameter top casing was fabricated to accommodate the Resonator clamp. A machined and polished centre spigot was attached to the clamp base which located and centered the clamp into the casing, but also offered a high pressure seal during pressure grouting. The clamp was connected and removed hydraulically, moved away from the centre opening of the casing during bar insertion and initial grouting and then re-introduced to form a grout seal and clamp attachment during extraction.

Figure 7. Resonator showing the drive casing and connection detail

The Resonator equipment consisted of a single 150 tonne crane with 40 m vertical leader, the RD 260 Resonator and power pack and a grout plant. The crew of 3 consisted of a crane operator, a front end man and the grout plant operator. The crane operator had a Resonator controller in the cab along with grouting and crane loading readouts. Frequent site visits and support were provided by PVE staff for training and equipment support. The Resonator production averaged 14 to 17 minutes for installation of the micropile casing, 12 to 17 minutes to flush the grout lines and fill the casing with grout and 17 to 20 minutes to extract the casing during pressure grouting. As a result typical production consisted of 1 micropile per hour or 7 to 9 micropiles per day. Micropile driving as rapid as 4 minutes for the full 34 m length was achieved. Higher productions are achieved with accurate tuning of the driving frequency to resonance and the correct blend of vibration amplitude and downward force. A common mistake is to over crowd or push on the pile while driving. This tends to dampen the vibration and alter the natural frequency of the system. Application of low downward push and allowing the Resonant vibration to do the work achieves the highest productions. Similarly on extraction, the use of too much pull can slow removal of the casing. While push and pull are required during install and extraction, the use of limited assistance results in the highest production rates.

Reliability of the RD 260 Resonator system proved to be poor at first with repeated electronic problems and fuse issues integrating the power pack to the control system for the Resonator. This was followed by mechanical issues which included isolator failures, and frequency motor stability problems. Over a period of weeks these issues were resolved and the Resonator provided more reliable service.

A major accident and safety issue occurred when the pile gate was left open during driving of the casing. The long, small dia pipe, despite a heavy wall, buckled under the crowd load in the absence of a midpoint lateral support. This caused the pipe to buckle, failing the clamp bolts and brought the casing pipe and clamp head to the ground. Fortunately there were no injuries. The Resonator operation was halted during the investigation. The Resonator program was renewed, but a change was made in the geometry of the frame applying the push and pull force. The Resonator is provided with an isolated yoke for pushing and pulling, however, the contractor had chosen to mount the leader guide directly to the backing mass of the Resonator by-passing the yoke isolation. This applied all loads directly through the internal biasing spring of the Resonator. Following this change and an upgrade to the power pack spool (frequency) circuit the mechanical issues with the Resonator dissipated and the project was completed with average productions of 40 micropiles per week.

This paper would not be possible without the co-operation and efforts provided by the staff of the BAM Contractors at the Rotterdamsebaan project and PVE – Dieseko Staff of Sliedrecht, Netherlands.