PILE PUSHING METHOD

THE BEST OF BOTH WORLDS

SUMMARY

In late 2016, Drukpaal.nl and A.P. van den Berg were the first companies in the Netherlands to start using the pile pushing method in combination with conventional precast concrete piles. Instead of traditional pile driving using a hammer, this system pushes precast concrete piles into the ground. This results in proven high-quality foundations that are installed without the usual noise and vibrations. Measurements performed so far (as every pushed pile is basically a compression test in its own right) seem to corroborate that the pile base coefficient (α_p) is 1.0 (instead of the factor of 0.7 used in the Dutch standard). Thanks to continuous recording of data, the pile pushing method offers excellent opportunities for quality improvement or responsible application of safety factors. For example, the fact that this piling method measures resistance from the moment of entry into the soil and throughout the pile pushing process, much like a cone penetration test, makes it possible to correlate the load-bearing capacity, cone penetration curve, and readings from the pushing force recording system to a demonstrable safety level through expert assessment. In other words, continuous pushing force recording will in future have to be considered a kind of (verification) cone penetration test that would make it possible to set the correlation factors (ξ) at 1.0.

Introduction

Traditionally, driving of precast piles has been among the more popular foundation methods in the European market, partly supported by the high quality and reliability of both the pile as well as the input method. However, because of regulations and environmental considerations the various methods that form the pile in the ground have grown in popularity. The downside of these methods is that they are more susceptible to quality variations in the piles (which are cast in situ), while these bored piling systems also tend to be more cost intensive. Pushing instead of driving high quality concrete piles into the soil combines the benefits of precast piles with a vibration-free and virtually silent pile pushing method, reducing nuisance for the surrounding area to a minimum. This is particularly welcome when installing foundations in inner city areas.

Drukpaal.nl is a company within the IJB-Groep. The pile pushing rig that Drukpaal.nl uses is supplied by Heerenveen-based A.P van den Berg GeoTechnology, the sole European distributor of hydraulic pile pushers built by China's T-Works. In Asia, this method has been used on a large scale for over a decade now. T-Works specializes in hydraulic pile pushers that deliver maximum pushing forces ranging from 600 kN to 12,000 kN. A.P. van den Berg adapts these rigs to ensure conformity to European legislation and regulations, particularly in terms of meeting European safety and environmental requirements, while also fitting T-Works' rigs with a data acquisition system. Since late 2016, a 320-tonne hydraulic pile pusher with a maximum pushing force of 3,200 kN has been used successfully in over 20 projects across the Netherlands with 3,000 pushed piles on a total length of 50,000 m. This article will go into experiences with the pile pushing method in the Netherlands so far, as well as into specific design aspects of using this new silent piling method with conventional precast concrete piles.

Description of the pile system and the hydraulic pile pusher

The hydraulic pile pusher is made up of a body frame with long side beams and short cross beams and a rail structure over which the body can move. This combination of side and cross beams allows the rig to move forwards, backwards and sideways, and even to rotate 360 degrees around the pile position.
The two side beams measure 11.8 m by 1.25 m, which, given the total rig weight of 320 tons, results in ground pressures of approx. 110 kPa per beam.

While maneuvering, the rig always rests on either the cross or side beams as the other beams are repositioned to move the rig. Besides the weight of the basic rig itself, counterweights are used to be able to get the maximum

July 2019

Sandro Katerberg - A.P. van den Berg GeoTechnology, Harrie Dieteren - CRUX, Guido Meinhardt - CRUX, Tahl Tekofsky - Drukpaal.nl

pushing force out of the rig. The rig is able to deliver this maximum force when a pile is pushed down through the center of the rig. The pile pushing mechanism consists of four hydraulic cylinders and a hydraulic clamp that grips the pile. Owing to the relative simplicity of the design, the hydraulic pile pusher requires low-maintenance. An additional pushing system (the so-called side piler) can be fitted on the front end of the machine body. However, the maximum pushing force that the side piler can deliver is only about 50% of the center piling system. The pushing mechanism (jack) can push a pile roughly 2 meters, followed by an interruption to move the clamp box up and grip the pile at a higher position. During the pushing process, depth and total pushing force are recorded automatically and continuously.

So far, this new piling method has been used to push square 250 mm to 350 mm precast piles with lengths ranging from 6 to 22 m. Based on current insights, the pushing method will also be able to handle piles of up to approx. 25 m long, as well as segmental piles. The use of a steel extension piece will furthermore make it possible to push piles to ground level or even below.

Load-bearing capacity calculation

At present, official pile load factors for this pile system (i.e. the type of pile combined with the installation method) are not yet available. In the absence of load test results, it is common practice to classify the 'new' pile system based on comparisons to pile systems that are already covered by the Dutch standard. Analyses of several pushed piles from the early days of this technique and from projects that have been concluded show that existing pile load factors used for driven precast piles lend themselves well for use with this 'new' pile system. During the design phase, the calculation of the bearing capacity of a pushed precast concrete pile is, therefore, approached as if it concerned a driven pile using values from Tables 7c and 7d of the NEN 9997-1 (2016).
It should be noted, however, that given current knowledge on pushed piles, a pile base coefficient (αp) of 0.7 seems to be on the low side (Van Baars 2018). Nonetheless, this value is still used until official load factors have been established based on pile load testing in accordance with NPR7201 (2017).

Pushing force prediction

Given the piling method, it is important to accurately predict beforehand how deep into the soil piles are expected to be pushed. To do this, a CRUX-developed program is used to predict the pushing force needed to push a pile down to the required depth. In principle, the force needed to statically push a pile into the ground equals the expected value for pile tip resistance plus shaft resistance.

Based on past analyses of recorded pushing forces, the maximum pile tip resistance is calculated using a pile base coefficient (αp) of 1.0 instead of 0.7, while pile tip strain (qb;max) is not capped at 15 MPa.

The influence zone below and above the pile tip is chosen between 2D/4D and 4D/8D. Although 4D/8D is a safe option for the design compressive resistance, it is potentially an overly favorable approach for the maximum expected pushing force, because the influence of unfavorable layers with diminishing cone resistance values is less significant.

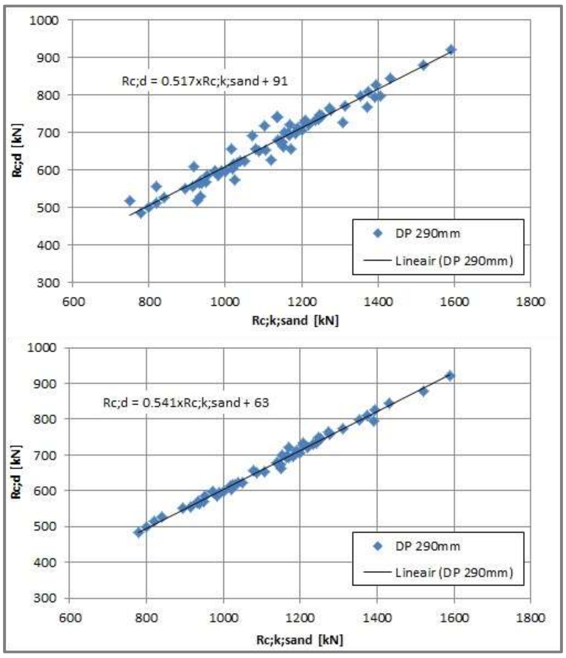

Figure 2 – **Calculated pushing force in sand ($R_{c;k;sand}$) versus design value bearing capacity ($R_{c;d}$) for a set of cone penetration tests and various pile tip levels.**

From the moment of insertion into the soil (at ground level), the pile is subjected to resistance on the tip and along the shaft. In light of this, skin friction (shaft friction) is also factored into the clay and unfavorable layers, from which, in line with the load-bearing capacity calculation, no shaft friction is derived. The pile load factor to use for the shaft in these unfavorable layers is determined based on Table 7d of NEN 9997-1:2016. In determining the maximum pile shaft resistance, cone resistance is not capped at 12 or 15 MPa, but actual values measured for cone resistance are used.
Given that the principle of pushing precast concrete piles into the soil is based on local displacement of soil under the pile tip, the partial resistance factors (γ_b and γ_s) and correlation factors (ξ) are set at 1.0. The total pushing force (Rc;k;total) needed is determined per level based on:
$R_{c;k;total} = R_{pile\ tip} + R_{shaft}$
It needs to be clear in advance which piles cannot be pushed through the center of the rig, as this has great implications for the maximum pushing depth and is consequently a crucial factor to consider when designing the piling plan.

Assessment of pushing force

As specified above, the pushing force prediction takes shaft friction into account from the moment of entry into the soil. When determining the design value bearing capacity, this is normally done from the top end of the zone where positive shaft friction is factored in, i.e. the foundation sand layer.

To establish a relation between the actual pushing force achieved (force data recording) and the loadbearing capacity calculated, shaft friction down to the foundation sand layer must be deducted from the total pushing force calculated. Plotting the load-bearing capacity ($R_{c;d}$ i.e. excluding negative skin friction) out against the calculated required pushing force in the sand (designated as $R_{c;k;sand}$) for each sub-area/CPT (Cone Penetration Test) and pile size will produce an equation as shown in figure 2. This should preferably be done for each sub-area/CPT over a length from at least pile tip level to approx. 2.5 m above that to obtain a more realistic comparison than when looking only at the pile tip level.

It is important here that the variation coefficient over this length does not exceed 12% and that the load-bearing capacity increases as the pile is pushed deeper into the soil. The equation thus derived can only be used to make an assessment of the force recorded if the predicted force matches the actual value measured. Therefore, figure 3 plots the pushing forces measured (force data recording) for two piles out against the predicted pushing force.

According to the prediction the pushing force in the sand at pile tip level would be approximately 1,590 kN with an average value of approximately 1,280 kN over the final 3 meters. For two piles that were installed nearby, piles 105 and 106, values of 1,330 kN and 1,550 kN respectively were measured at pile tip level and values of 1,210 kN and 1,310 kN respectively along the pile length above the pile tip.

Especially for the bottom section of the graph, the prediction is well aligned with actual values measured. Load-bearing capacities calculated along this length have a variation coefficient of 5% to 10%, as also reflected in the pushing forces measured (recorded data) in the sand.

Based on the extrapolated comparison in figure 2, a reliable indication of the load-bearing capacity can be given for piles 105 and 106, namely approximately 780 kN and 900 kN respectively. The negative friction, as determined based on the design CPT's, can (depending on the soil composition) subsequently be deducted, given that the pushing force graphs do not give grounds to adjust this value.

Experience gained in previous projects

Every pushed pile basically constitutes a kind of compression test, as also shown by the example of assessment of readings from the pushing force recording system in this article and the example in figure 4. Based on projects completed so far, the pile base coefficient (αp) with this piling method is more likely to be 1.0 rather than the 0.7 from the Dutch standard. This is despite the fact that a large number of pushed piles are over 8 meters in the sand. It is noted, however, that the tip-to-shaft ratio has not yet been determined exactly using sister bars/strain sensors, but is instead based on assumptions. This can be a subject for follow-up studies.

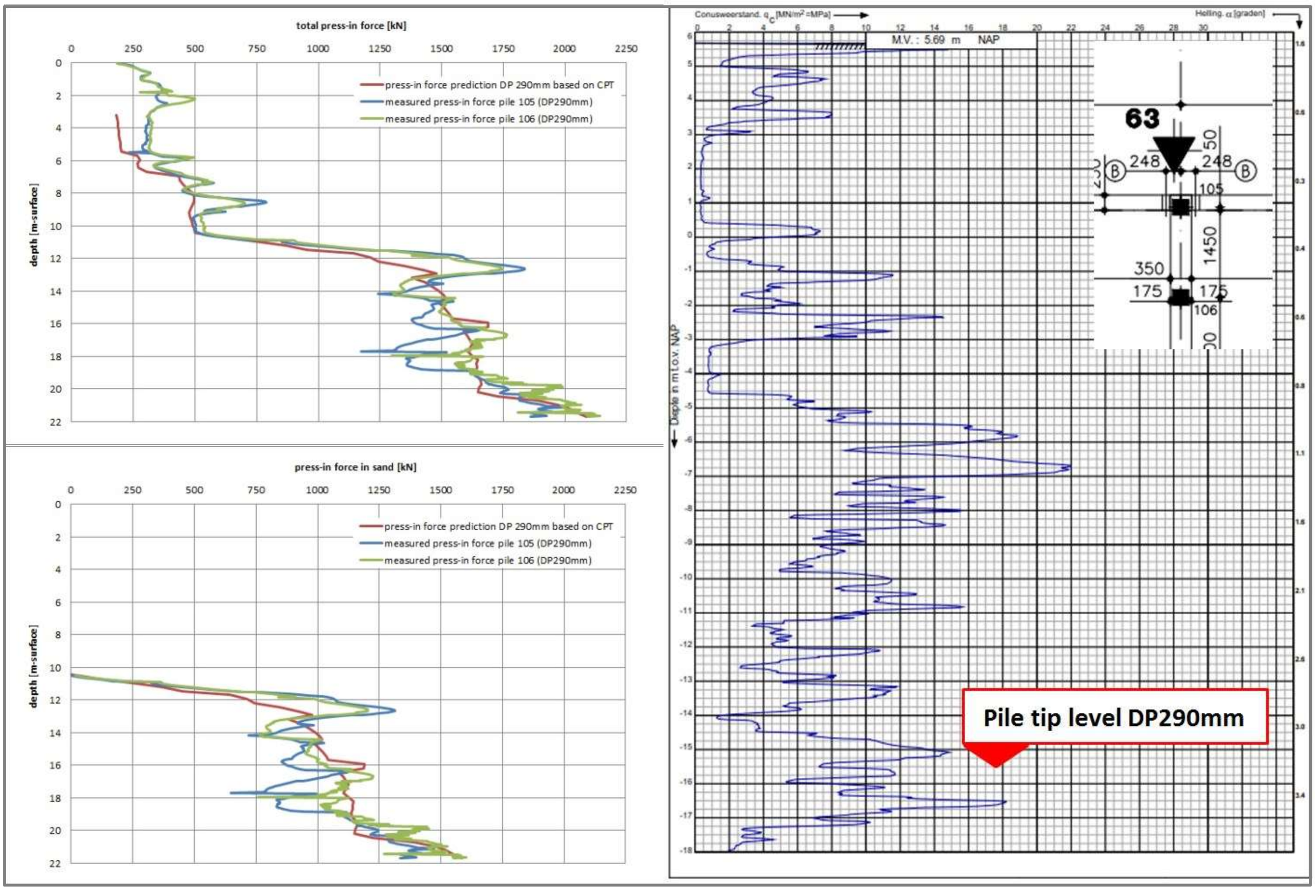

Figure 3 – Calculated versus measured pushing force (top: total; bottom: in the sand).

Design and execution aspects

The pile pushing method (i.e. installation of precast concrete piles using the pushing method) combines the quality benefits of precast concrete piles with the silent and vibration-free characteristics of auger piling systems. These latter systems do, however, require extra effort in terms of quality monitoring, because they involve foundation elements that are cast in situ. Continuous total force recording during pushing gives this piling method further quality benefits.

Focus points to consider with this piling method are the weight required and the dimensions of the hydraulic pile pusher, accurate prediction of the achievable pile tip level (also in relation to the required load-bearing capacity) and incorporation of this system in foundation designs at an early stage. These aspects will be addressed successively.

Rig weight affects the load-bearing capacity of the subsoil, as well as the possible influencing of objects in the immediate surroundings (such as adjacent buildings, embankments, sheet piling, and cables and pipes) and requires expert assessment through a risk analysis. In principle, the rig can push a pile positioned as close as approximately 0.8 m to an adjacent building (pushing force of approximately 50%).

If the subsoil requires the use of dragline mats, it is advisable to align the piling pattern with the mats.

During the design phase, there should also be extra focus on compacted to highly compacted sand layers, because these are difficult to pass. If the maximum allowable pushing force is reached above the required pile tip level, the pile will have to be cut off before work on the next pile can start. A robust assurance concerning feasibility of the piling depth (pile tip level) is therefore recommended. Consequently, it may be advisable to, based on the pushing force prediction, use more shorter piles with possibly larger diameter rather than fewer but longer piles. Performing extra CPT's when facing varying soil conditions will also reduce the risk profile with regards to the feasibility of the required pile tip level.

The hydraulic pile pusher is suited particularly for projects of some scale (>50 piles). For projects with a regular piling pattern (for example, line infrastructure such as tunnels, approach slabs, noise barriers) or house and utility building projects, where early alignment of piling plans with this new piling method is possible, the pushing method offers clear benefits in combination with the absence of inconvenience caused by nuisance and vibration, a high speed of construction and proven high quality.

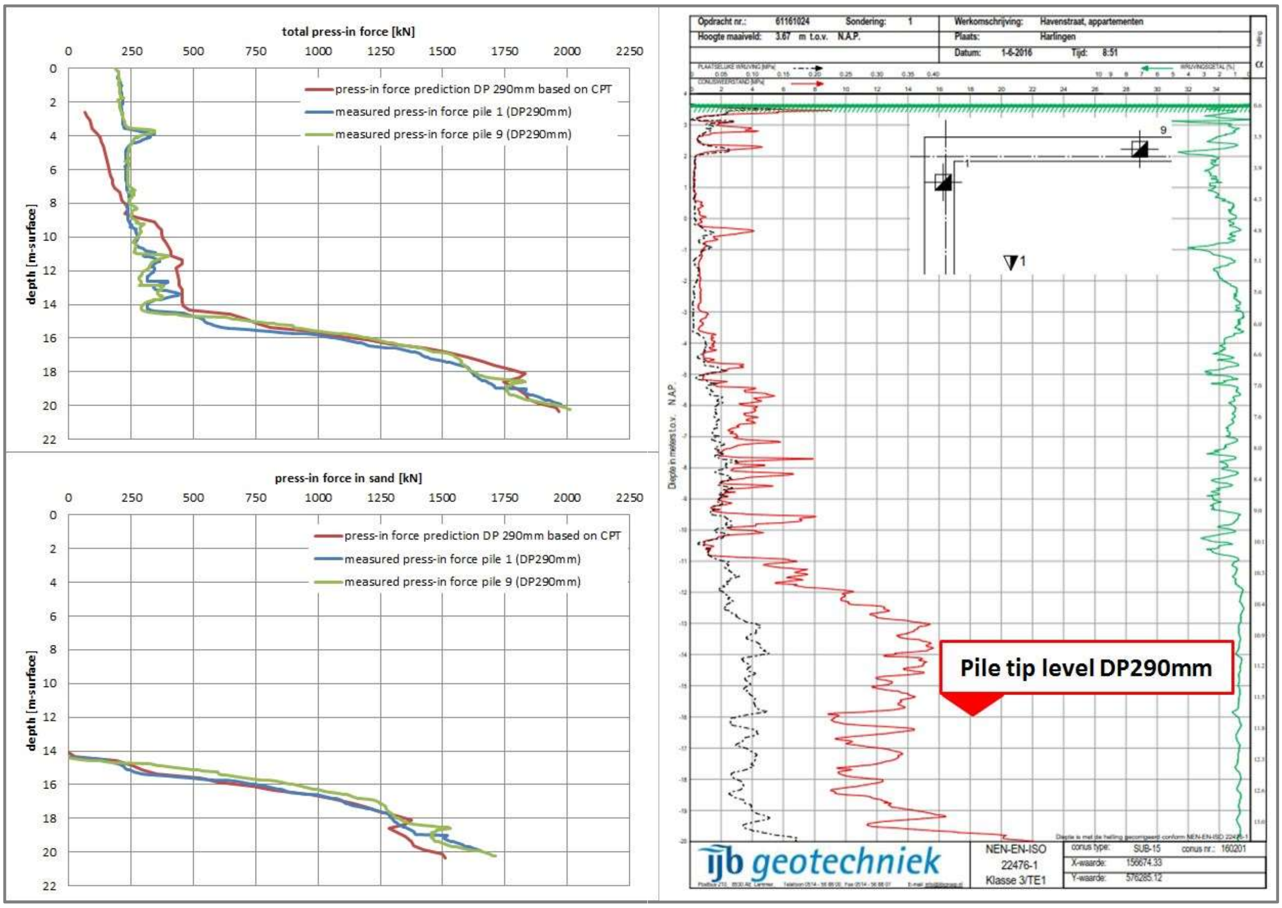

Figure 4 – **Calculated versus measured pushing force (top: total; bottom: in the sand).**