Influence of grout injection parameters on shaft bearing capacity of screw displacement piles

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ABSTRACT

This document describes the test program that was conducted in 2021 to investigate the influence of grout injection parameters on the shaft bearing capacity of screw displacement piles. Grout variants considered were water/cement ratio, blend composition and flow rate. This resulted in 5 groups of 3 test piles with more or less the same grout parameters. Other installation parameters were kept constant. Back flow grout was sampled to determine composition and properties. Static load tests in tension until failure were used to determine the shaft bearing capacity of the test piles. In total 7 out of 15 test piles were extracted afterwards to establish the pile diameter. Also the annulus of the extracted piles was cored with the purpose to obtain the shear properties of the grout/concrete interface of the piles. It can be concluded that the range of water/cement ratio's applied in the test program did not have a substantial influence on the bearing capacity of the test piles and that the applied highest grout flowrate seemed to be at the limit of becoming influential. Furthermore it was found that the empirical cone resistance factor for shaft resistance (α_t according NEN 9997-1) is in compliance with the generic value of 0.009 for sand layers for this type of pile, provided that a limit value of 15 MPa for the cone resistance q_c is not applied and provided that the shaft bearing capacity is computed based on the outer diameter of the screw tip.

Keywords: screw displacement pile, grout injection, water/cement ratio, bearing capacity

1 INTRODUCTION

Screw displacement piles are increasingly applied in the Netherlands as an alternative for driven piles, when noise or vibration restrictions are applicable. One can discriminate 2 main types of these piles: cast-in-place piles installed with a temporary steel casing (i.e. "Fundex"), see Fig. 1, or piles having a permanent steel casing (i.e. "Tubex"). It is common practice to install these piles using grout injection via a central (retracted) grout tube, where grout is injected horizontally through multiple grout ports at the very top of the conical screw tip. The grout provides lubrication in sandy soils during penetration, cools the screw tip/casing and in sand layers creates an annulus of cemented sand around the concrete core/permanent steel casing. This annulus increases the shaft bearing capacity of the pile. It is frequently suggested that one should apply water/dry ratio's between 0.45 and 1.25, as applied for other piling systems (i.e. micropiles; see execution code EN 14199). This seems correct for small diameter piling systems with little soil displacement, but is not common practice for the screw displacement piles. Furthermore piling crews will adjust grout parameters during pile installation to maintain the lubricating effect of the grout and achieve acceptable penetration rates. To demonstrate that water/dry ratio's and flow rates for grouts used in practice are sound, ten Dutch piling contractors, all members of the Dutch association of foundation contractors (NVAF) and all experienced in the application of this pile type, decided to fund a test program to be executed in 2021. An execution protocol drafted by NVAF in 2021 was tested to verify advised grout flow rates.

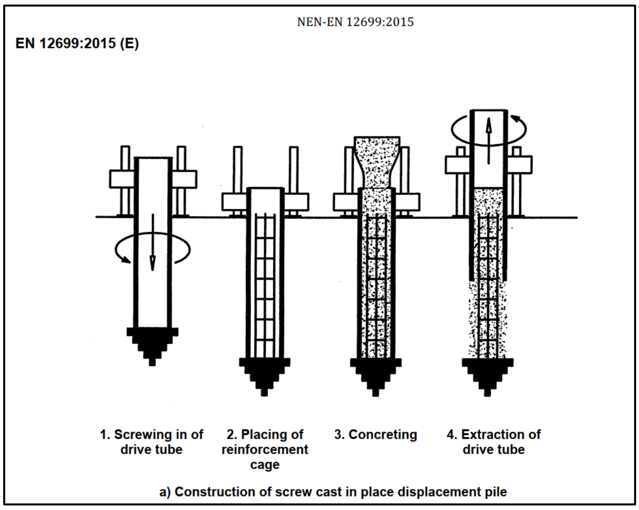

Fig. 1. Installation sequence for screw displacement pile with temporary casing.

2 TEST PROGRAM

The test program comprised the investigation of five grout variants, designated A through E. For each variant three test piles were installed and tested, i.e. A1 through A3. The variants are shown in Table 1.

Table 1. Variants for test piles.

Variant	grout	w/d	Flow [l/min]
A	Cement	1.25	75
B	Cement	2.5	75
C	Cement	3.75	75
D	Cement	2.5	115
E	GM42	2.0	75

Cement used was of type CEM III/B 42,5; variant E was a commercially available mixture, brand name Webertec GM42 (cement content 70 % by weight), thus water/cement ratio is in range of the other variants. Grouts did not contain any other constituents.

Fig. 2. Screw tip Ø 380/470 mm

Selected size for the cast in place screw displacement piles with grout injection was a nominal concrete shaft diameter of 380 mm (determined by the size of the drive tube crown) and an outer screw tip diameter of 470 mm. The screw tip was of conical shape, see Fig. 2. The grout flow was based on the NVAF execution protocol which asks for a maximum grout flow of 760 liter/min per m^2 of displaced area. For dense sand layers this may be increased to 800 l/min per m^2. Here the displaced area is determined by the crown diameter, equaling 0.113 m^2 giving an ultimate allowed flow of 91 liter/min. Thus 115 liter/min is set well above the limit value. Test piles were installed and tested at a site in Lemmer, Netherlands. First a soil investigation was performed, comprising CPTs and borings to classify the soil. For each CPT, predictions were made for the expected pull out forces during the static load testing of the test piles. Test pile locations were selected in such a manner that expected failure loads for the 3 piles per variant showed the lowest mean squared error. Pile installation parameters (i.e. screw torque, rpm, pull down, rate of penetration) were logged. Back flow grout was sampled during pile installation to observe grout properties (density, strength). Post pile installation CPTs were executed to examine possible soil changes (increase / decrease of cone resistance). Static load testing was performed more than a month after pile installation, in line with NPR 7201 to assure sufficient strength for both the concrete pile and its cemented sand annulus. Finally one or more test piles per variant were extracted to determine the diameter of the pile annulus. Some extracted piles were sampled by coring perpendicular to the pile axis to establish the properties of the grout/concrete interface.

3 SOIL INVESTIGATION

A geotechnical site investigation was executed to determine soil properties of the Lemmer test site. In total 18 CPTs were executed in 2 rows of 9, see Fig. 3. Distance within a row of CPTs was 2.7 m; distance between the 2 rows op CPTs was 9 m. In addition 2 borings A and B were conducted to identify soil layers, take sand samples and observe the ground water level. The subsoil is in general composed of a top layer of crushed sandy stone, underlain by a peat layer under which a first fine sand layer. This was the intended layer for pile installation. CPTs were executed according application class 2 (NEN-EN-ISO-22476-1), with cone resistance accuracy of 5 % (100 kPa minimum).

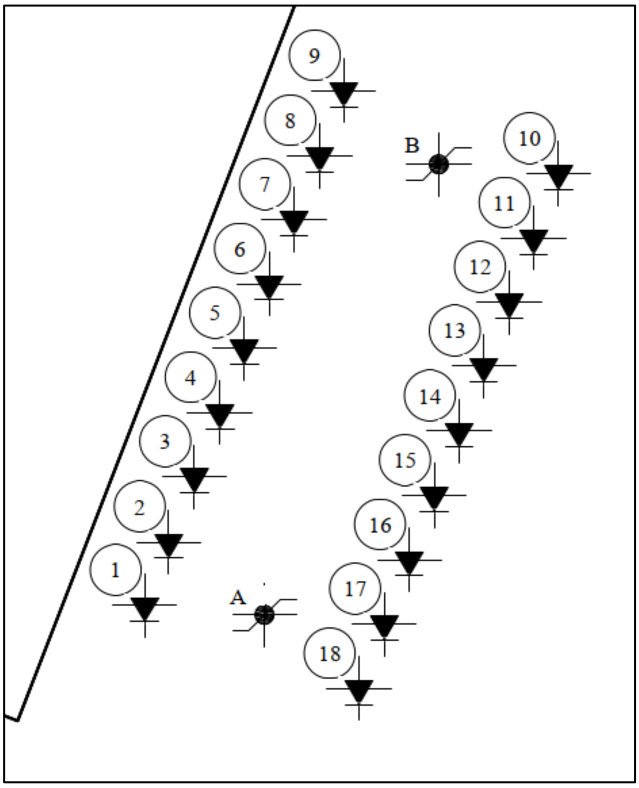

Fig. 3. Plan View of soil investigation Lemmer

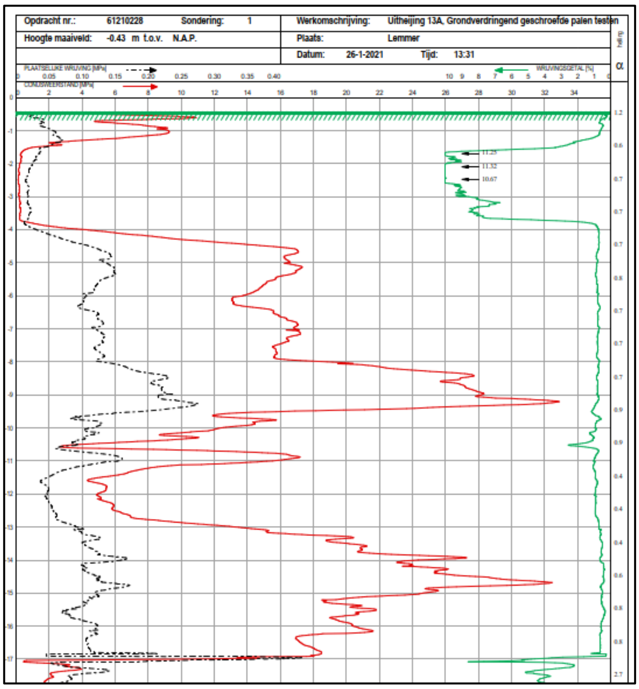

Fig. 4. Typical CPT for Lemmer test site

The first fine sand layer between 3.5 m and 9 m below existing grade (EG) shows a d_{50} of 0.14 mm. Ground water level was around 1.2 m below EG.

4 PREDICTIONS

Predictions for the pull out force of the piles were made by ignoring the shaft friction in the shallow top soil layer (which was loosened after pile installation) and only accounting for the friction in the first fine sand layer, aiming for an embedded length of appr. 5 m. The predicted soil shear at failure for the pile was assumed equal to the product of the cone resistance and the empirical cone factor α_t of 0.009 without limitation for the cone resistance. Thus for each CPT a failure load was computed. Subsequently 15 CPTs were selected as potential test pile positions and finally these 15 CPTs were grouped per 3, having more or less similar expected failure loads (least squares). Expected failure loads per grout variant ranged from 1000 kN to 1400 kN.

5 PILE INSTALLATION

Prior to installation of the test piles, 3 dummy piles were installed (without rebar cage) to calibrate grout manufacture, grout pump speed, screw torque and screw rpm. Test piles were installed aiming for a penetration speed in the fine sand layer of less than 1 m/min. In practice this proved to be 0.25-0.5 m/min. A typical graph of the installation of a test pile is shown in Fig. 5 (test pile A1). Graphs show multiple installation parameters as a function of penetration depth (here being 9.2 m).

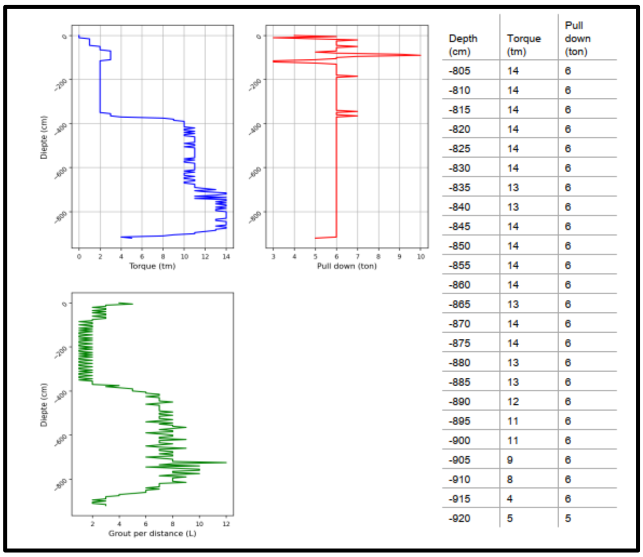

Fig. 5. Example of pile production graph

Back flow grout was sampled at 2 levels of penetration of the fine sand layer, see Fig. 6. The composition of the injected grout was close to the nominal intended grout mix, as did the flowrate of grout. In Table 2 the grout parameters are shown, where "density-out" refers to the average back flow grout density and the strength was determined on samples of the back flow grout using prisms tested in compression at age 56 days. The difference in density-out for type B and type D is caused by the applied grout flow rate, being 115 l/min for type D.

Fig. 6. Sampling of back flow grout

The back flow grout strength does not show a comparable difference between type B and D, indicating that the cement content for the back flow grout has more relevance than the flow rate. Densities for the back flow grout are higher than for the injected grout, due to the filtering effect of the fine sand layer and due to pick up of sand particles.

Table 2. Grout installation parameters

Variant	w/d ratio	w/d ratio	density in	density out	strength j=56
	[aimed]	[test]	[kg/l]	[kg/l]	[MPa]
A	1.25	1.29	1.40	1.76	13.3
B	2.5	2.62	1.23	1.80	6.9
C	3.75	3.77	1.16	1.75	2.4
D	2.5	2.57	1.27	1.68	6.7
E	2.0	2.52	1.23	1.73	3.1

6 POST SOIL INVESTIGATION

After test pile installation additional CPTs were executed in an attempt to examine potential change in the cone resistance of the fine sand layer due to the installation effect of the piles (soil displacement should lead to noticeable increase of cone resistance in the vicinity of the pile shaft). At all 15 test pile positions, 2 post CPTs were executed West and East of the pile position at 0.75 m distance. Thus post CPTs 101 (West) and 201 (East) belong to CPT 1. Post CPTs 103 and 116 are located near CPTs 3 and 16 and serve as check measurements to establish variability of the soil.

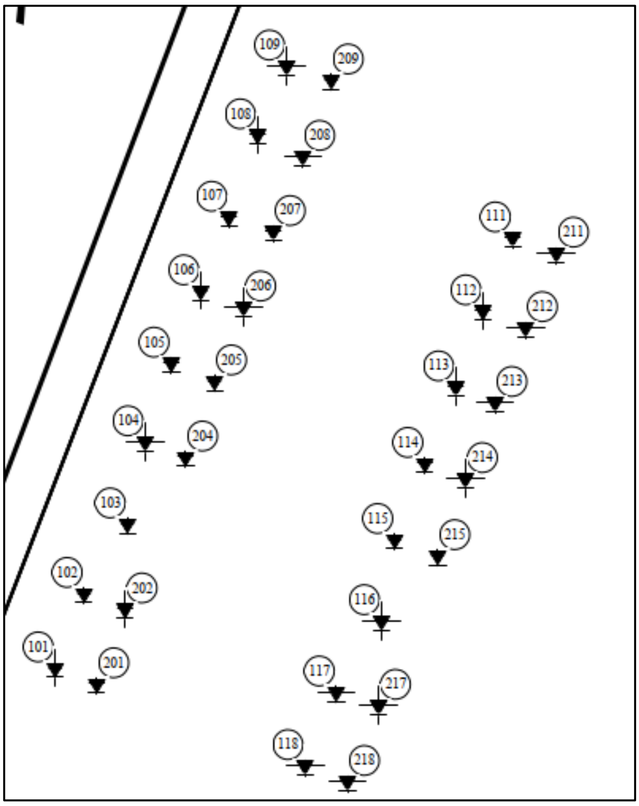

Fig. 7. Plan view post CPTs

Both pre and post CPTs were executed with inclination measurement, thus allowing to deduct the distance to the piles.

Table 3. Pre and post CPT results

Variant	Q_c pre	ΔS	$ΔQ_c$ west	ΔS west	$ΔQ_c$ east	ΔS east
	[MPa]	[m]	[%]	[m]	[%]	[m]
A	14.4	0.26	17	0.80	48	0.60
B	16.2	0.22	9	0.87	21	0.71
C	18.4	0.18	27	0.74	15	0.68
D	18.7	0.32	-1	0.96	-1	0.69
E	16.7	0.27	17	0.73	23	0.83

Table 3 shows the average cone resistance Q_c for the pre-CPTs in the sand layer and the average distance ΔS of the CPTs to the test piles; similarly the average cone resistance improvement and distance is given for the west and east post CPTs. Correlation between cone resistance improvement and distance is poor (resp. 0.57 and -0.53), most likely due to variability of the soil, which is also shown by comparing control CPTs 3 with 103 and 16 with 116, both showing an average decrease in cone resistance of respectively 15 % and 11 % at 0.3 m and 0.48 m distance from each other, whilst no piles were installed here. At best one can conclude that test piles series A, B, C and E show an average cone resistance improvement of 22 % and series D show no improvement.

7 STATIC LOAD TEST

All 15 piles were subjected to a static load test in tension until failure. Load testing was conducted using a simple double H-beam frame with a center jack. The beam had a free span of 8 m and was supported with crane mats, see Fig. 8. Load tests were conducted in compliance with a type B test as per Dutch Code NPR 7201. In total 8 load steps were applied, with an unloading step after load step 4. Pile failure was set at a permanent pile head deformation of 47 mm (10% pile diameter). Creep was set at 2 mm and observed at every load step up to 4 hours, after which the next load step was halved. In general each pile test took a working day. No strain gauges or tell tales were used for the test. Only pile head deformation was measured and the applied load.

Fig. 8. Test set up

The results were in close proximity of the predicted failure loads; difference between predicted pull out force and measured pull out force was in general within 10 % of the predicted value, see Table 4.

Table 4. Static load test results

Variant	w/d ratio	$F_{predict}$	F_{test}
	[aim]	[kN]	[%]
A	1.25	1027	99
B	2.5	1126	110
C	3.75	1311	98
D	2.5	1342	89
E	2.0	1165	105

8 PILE INSPECTION

For each pile variant one or more piles were extracted after the static load tests to inspect the piles. A total of 7 piles were extracted and cleaned. Subsequently the shaft circumference was measured from top to bottom. It showed that piles had shaft diameters, along the section that had been present in the fine sand layer, similar to the pile tip diameter of 470 mm, being somewhat bigger around the pile tip and slightly smaller towards the section that had been sitting in the peat layer. The pile section that was located in the peat layer had more or less the diameter of the concrete core, being appr. 380 mm. Finally the pile top showed again some increase in diameter.

Fig. 9. Extracted piles with screw tip in front

Average encountered pile diameters in the fine sand layer are given in Table 5.

Table 5. Pile shaft diameters in fine sand layer

Variant	w/d ratio	Amount	$Ø_{average}$
	[aim]	[-]	[mm]
A	1.25	2	478
B	2.5	2	474
C	3.75	1	496
D	2.5	1	468
E	2.0	1	484

9 PILE CORING

Various cores were taken from the extracted piles to see if one could determine the shear capacity of the grout/concrete interface. Results were quite random and showed no clear correlation with water/dry ratio of the grout. Failure of test specimens occurred mostly within the grout layer and not at the grout/concrete interface. Compressive stresses showed to be 3.8 MPa on average for variants A-D and 1.1 MPa for variant E (for which a strongly deviating result has been neglected), whilst shear stress showed to be 0.43 MPa on average (once again one result being too positive neglected). Reliability is low (variation coefficient 40 %). Despite this, the grout/concrete interface survived the pull out tests without showing structural failure; only geotechnical failure had occurred.

10 CONCLUSION

Cast in place screw displacement piles with grout injection were installed and tested in Lemmer, Netherlands. Applied variation of water/dry ratio for the grout between 1.25 and 3.75 did not show significant differences for bearing capacity in tension. A mixture of cement and limestone dust having an effective water/cement ratio of around 3 showed similar performance. Grout flow was a constant 75 liter/min with penetration speeds in between 0.25 and 0.5 m/min in the bearing stratum. Grout flow of 115 liter/min looks to be near the limit for this pile size, looking at pull out test results being lower than predicted on average, albeit that this is predominantly determined by a single deviating result.

Post CPT results proof the heterogeneous character of the bearing stratum and do not show undisputed improvement or reduction of cone resistance due to the pile installation, although on average one can notice an increase in cone resistance. The empirical cone factor for shaft resistance of 0.009 for this type of pile shows to be correct, provided that shaft bearing capacity in sand layers is determined based on the pile tip diameter and not the casing or drive tube diameter. Cone resistance values should not be limited to 15 MPa for computing the shaft bearing capacity in tension. Grout flow rates set in the NVAF execution protocol do not hamper bearing capacity for this pile type.

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