

MICROPILES IN THE NETHERLANDS

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ABSTRACT

In The Netherlands micropiles are frequently used as economic and reliable tension elements to prevent uplift of underground structures due to water pressures. The generally high ground water table throughout the country is well known worldwide.

As the available geotechnical and structural codes do not cover all specific design aspects of these slender and highly execution-sensitive piles, the Dutch guideline CROW-CUR Report 236 Ankerpalen (in Dutch “Ankerpalen” is a synonym for micropiles mostly under tension, or “anchorpiles”) proved to be indispensable to ensure their safe and sound use. Since the publication of its first edition in 2011, it has not only served as a basis for design but also to demonstrate load-bearing capacity through the assessment of execution parameters and the conducting of pile tests.

This paper outlines the most important topics regarding the use, geotechnical design and testing of anchorpiles as per common practice in The Netherlands, based on the guideline as mentioned above.

HISTORY

During several decades micropiles were well known in The Netherlands for their use as compression piles in renovation projects and foundation improvement of old houses and small structures with limited access. Since the early 1990's however, there has been a strong increase in the use of micropiles as “anchorpiles” to secure the stability of (temporary) under water concrete floors, structural concrete slabs as part of underground basements, ramps on both end of closed tunnels, etcetera. The knowledge on how to design and execute these piles was introduced by Dutch and German specialist foundation contractors involved in large building projects in Berlin, where deep basements were constructed and so called GEWI®-piles were installed. One of the first underground projects in The Netherlands using the so called GEWI®-piles was in 1995 in the city centre of Alkmaar, where a large underground parking garage was built.

These GEWI®-piles were used as an alternative for precast concrete piles that was the predominate type of tension pile used at that time in The Netherlands. It's interesting to mention that these concrete piles were already delivered on site, but not installed after huge discussions about the potential disastrous impact of piledriving at close distance of relative old adjoining buildings, see Figure 1. The anchor piles that were installed instead saved the project, because of their low noise and low vibration during execution of the piling works.



Figure 1. Construction of underground car park in the city of Alkmaar.

Since then anchorpiles became increasingly popular in large and deep infrastructural projects, such as in deep construction pits at both ends of several bored tunnels in the so called “Betuwe Route” a cargo railway line between the Port of Rotterdam and Germany.

It's important to understand that in these years there was no Dutch geotechnical code or likewise for vertical ground anchors, so geotechnical (anchor)pile design was more or less a combination of (personal) empirical experience and the German DIN4125 “Verpressanker” (Ground anchors with pressurised grouted bond length) as used for inclined ground anchors to support retaining walls. The quality of the execution of anchors and micropiles or anchorpiles was also strongly dependent on the craftsmanship of the personal operating the drilling rigs.

OVERVIEW OF ANCHORPILES USED IN THE NETHERLANDS

Anchor piles are slender, in-situ formed foundation elements, with shaft diameters ranging from approximately 150 mm to 400 mm. Pile lengths of 20 to 30 meters with pile loads between 100 kN and 1,000 kN are common. More specialized applications are also possible, involving longer piles embedded up to approximately 65 m below ground level and with bearing capacities (both tension and/or compression) reaching 2,000 kN to 2,500 kN. Central solid bars or rolled tubes serve as structural elements to transfer the tensile and/or compressive loads to load-bearing soil layers .

For certain types of anchorpiles, the anchoring bond lengths are formed by injecting the grout mixture under increased pressure, while for other types, grout is applied more or less hydrostatically.

In current Dutch practice, the anchorpile systems are distinguished on the bases of method of installation, the method by which the grouted body is formed in the load-bearing soil layer and the type of structural, steel element.

Table 1. Available types of Anchorpiles in The Netherlands.

Method of installation		Pile diameter [mm]	Formation of grouted body in load bearing soil layer	Structural element
A	Double drill casing with internal flush anchor piles	180 – 200	Pressure grouted from pile tip upwards, full length	hot-rolled solid bars with ribs, or cold-rolled massive <solid?>bars with thread
B	Single drill casing with external flush anchor piles	180 – 250	Pressure grouted from pile tip upwards, full length	hot-rolled solid bars with ribs, or cold-rolled massive <solid?>bars with thread
C	“Self” drilling anchor piles	180 – 400	Groutinjection (wcr > 1.0) during drilling, post grouting (wcr 0.50) from pile tip upwards. Possibility to create an extra post grouted pile tip	cold-rolled, thick-walled hollow steel tubes
D	Screwed anchor piles	180 – 350	Groutinjection (wcr > 1.0) during drilling. Possibility to create an extra post grouted pile tip.	cold-rolled, thick-walled hollow steel tubes
E	Vibrated anchor piles with a temporary steel casing	168 – 250	Groutinjection (wcr 0.50) from pile tip upwards over full length	hot-rolled solid bars with ribs, or cold-rolled massive <solid?>bars with thread

See figures 2 and 3 below for details of drilling heads and structural elements.



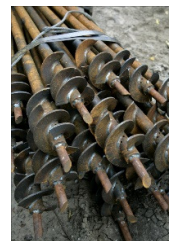
A Double drill casing with internal flush



B Single drill casing with external flush



C “Self” drilling



D Screwed



E Vibrated with temporary steel casing

Figure 2. Available types of Anchorpiles in The Netherlands.



Hot-rolled massive bars with ribs



Cold-rolled massive bars, with thread



Cold-rolled, thick walled hollow steel tubes

Figure 3. Structural elements.

Depending on several criteria, piles are installed either from existing ground level or from pontoon after a wet excavation of the construction pit, as shown in figure 4.



Figure 4. Pile installation.

GUIDELINE CROW-CUR REPORT 236 - ANCHORPILES

History and reasons for developing the Guideline for Anchorpiles

The first edition of the guideline was published in 2011 and was the result of five years of research and discussions on the behaviour and bearing capacity of this specific pile type. The term “anchorpiles” (or “micropiles”) in The Netherlands refers to all non-driven pile systems (bored, in-situ formed anchoring elements), which were originally used primarily for sheet pile anchoring. However, with or without modifications, these systems have also proven suitable for use as vertical tension (and compression) piles underneath (underwater) concrete floors and other structures.

The motivation for drafting the guideline was the experience gained during the construction of the Hubertus Tunnel in The Hague in 2005. As the progress in piling was very low (first piles took more than one day per pile) and several problems occurred such as clogging of the grout pipes and a deviant and unexpected grout consumption, concerns grew about the quality of the piles installed. It was decided to perform load tests on several piles, and then it appeared that piles geotechnically failed at just 30 to 60% of the expected tension capacity. After carefully extracting one of the failed piles, it became clear that grouting of the pile shaft went terribly wrong, as can be seen in the pictures below.



Figure 5. Failed grouting of the pile shaft.

After analysing the situation it was concluded that the main causes were to be found in the inexperienced piling crew and the specific characteristics of the fine and rounded sand particles in the project area (dune sands).

These experiences were documented in the Dutch journal “*Geotechniek*” edition of October 2006, where lessons learned were presented regarding the use of anchorpiles. These lessons learned remain the foundation of the guideline. However, through continuous feedback from new practical experiences, the guideline has been kept up to date via the 2016 addendum and the second revised edition in 2017, incorporating newly acquired knowledge.

The third edition, which was published at the end of 2023, includes updates based on experiences from recent years. Since the guideline is very specific for Anchorpiles it is an important addition to general geotechnical standards, which do not sufficiently address the specific aspects and behaviour of anchor piles.

Objectives and contents of the Guideline

The main objective of the guideline is to ensure both geotechnical and structural quality of anchorpiles. This is obtained by a comprehensive approach of using the right values of the friction between the pile shaft and the adjoining load-bearing soil layer(s) in combination with pile testing by static load tests, on site independent supervision and expert judgement on the essential execution parameters as registered during the piling works.

The publication contains a description of various anchorpile systems, design rules for bearing capacity (both tension and compression) and axial behavior (spring stiffness), requirements regarding the steel properties, corrosion protection, and quality assurance.

Design approach

Anchorpiles have specific characteristics that differ from more traditional foundation piles.

Execution sensitivity and quality assurance are key factors with regard to the bearing capacity of this type of piles. This has resulted in a specific philosophy for anchor piles in which a strict distinction is made in the geotechnical pile design depending on whether or not piles are being tested:

Option 1

The preferred option is to test the anchor piles on site (Static Load Test):

- a. prior to the start of a project: investigation tests on a minimum of 3 piles that will be loaded (tension) until geotechnical failure;
- b. the ultimate registered load where the creep criterium $k_s \leq 2.0$ mm, is used to determine the optimized design value for the friction between the pile shaft and the adjoining load-bearing soil layer (in case the pile penetrates through two or more different soil layers, even if they are both sand layers, each layer must be tested individually);

- c. after completion of the piling: suitability tests (tension) on a minimum of 3% of the production piles, with an absolute minimum of 3 piles, to verify the shaft friction and load-displacement behavior.

If this option is chosen, in addition to the pile testing a stringent supervision of the piling and expert judgement on the essential execution parameters is mandatory.

Option 2

In case the anchorpiles cannot or will not be tested (because of economics in the case of a relative small number of production piles, limitations in the project schedule or other restraints), higher safety in design is necessary. This is obtained by using safe lower bound design values for the friction between the pile shaft and adjoining load-bearing soil layer(s).

If this option is chosen, there is no requirement for supervision and expert judgement on the execution parameters.

GEOTECHNICAL DESIGN

Bearing capacity

The calculation of the bearing capacity for anchor piles basically follows the standardized calculation rules from the Dutch Geotechnical Code NEN 9997-1 (which includes EN 1997-1). Because of the specific behaviour of anchorpiles, different from regular more rigid types of foundation piles, two additional influences must be taken into account:

- a. limiting of the shaft friction along the top part of the pile shaft for tension-loaded anchorpiles when a firm load-bearing soil layer is found just below the excavation level;
- b. the so called length-effect or efficiency of the bond length for tension-loaded anchorpiles,

In general the bearing capacity of anchorpiles is calculated as follows:

- Pressure: $R_{c;d} = \pi \cdot \varnothing_s \cdot f_1 \cdot f_2 \cdot f_3 \cdot \alpha_s \cdot q_{c;red} \cdot L_s / \gamma_s \cdot \xi + 1/4 (\varnothing_s)^2 \cdot \alpha_p \cdot q_{c;red} / \gamma_s \cdot \xi$ (1)

- Tension: $R_{t;d} = \pi \cdot \varnothing_s \cdot f_1 \cdot f_2 \cdot f_3 \cdot \alpha_s \cdot q_{c;red} \cdot L_s / \gamma_{s;t} \cdot \xi$ (2)

where:

- $\varnothing_s$ = diameter of pile shaft, in m
- L_s = effective bond length of grout body, in m
- f_1 = factor for pile installation (=1,0 for all types of anchorpiles, both under pressure and tension)
- f_2 = reduction factor related to the so called group-effect
only in case of tension, depending on de centre-to-centre distance between the surrounding piles (the closer the ctc-distance the lower the f_2 - value <1,0)
- f_3 = reduction factor or “efficiency factor” related to the so called length-effect of the bond length

only in case of tension, depending on the bond length and the effective tension stresses in the steel element (the longer the bond length and the higher the stresses in the structural steel element, the lower the f_3 -value < 1,0)

- α_s = friction factor for piles under compression-loads
- α_t = friction factor for piles under tension-loads
- α_p = base resistance factor
- $q_{c;red}$ = cone resistance (CPT-value), in kN/m^2
reduced for excavation within the construction pit
- γ_s = safety factor for bearing capacity under pressure
- $\gamma_{s;t}$ = safety factor for bearing capacity under tension
- ξ = factor depending on the number of representative CPT's within the construction pit and the rigidity of the structure

The friction τ between the pile shaft and the adjacent load-bearing soil is defined by:

- Pressure: $\tau = \alpha_s \cdot q_{c;red}$ (3)

- Tension: $\tau = \alpha_t \cdot q_{c;red}$ (4)

And as anchorpiles in most cases are tested and subjected to a tensile load, it is assumed (safe approach) that:

- $\alpha_s = \alpha_t$ (5)

For calculation of the geotechnical bearing capacity, see the values for the shaft friction and base resistance as presented in table 2 below.

Table 2. Design values for geotechnical bearing capacity in sand.

Type of anchor pile		Shaft friction		Base resistance	Limit values	
		Optimized (option 1)	Lower bound (option 2)		CPT-value [MPa]	Friction [kPa]
		$\alpha_s = \alpha_t$	$\alpha_s = \alpha_t$	α_p	q_c	τ
A	Double drill casing with internal flush anchor piles	0,015 – 0,0225	0,011	0,30	20	450
B	Single drill casing with external flush anchor piles	0,017 – 0,025	0,011	0,30	20	500
C	“Self” drilling anchor piles	0,012 – 0,015	0,008	0,30	20	300
D	Screwed anchor piles	0,012 – 0,015	0,008	0,30	15	225
E	Vibrated anchor piles with a temporary steel casing	0,015 – 0,0225	0,010	0,30	20	450
-	Other than A to E	-	0,006	0,30	15	-

Note 1: For option 1 and 2 see the earlier paragraph *Design approach*.

Note 2: In case of option 1 values (project specific only) to be used in final pile design are to be determined by executing investigation tests prior to the actual piling works.

Limiting Shaft Friction in Tension-Loaded Piles

When a load-bearing soil layer is located just below the excavation level or ground level, caution is required. Strictly following the standardized design rules, see previous equation (2) may lead to an overestimation of the tensile bearing capacity. The upward force transfer from the pile shaft to the surrounding soil may be calculated as larger than the actual effective weight of the surrounding soil.

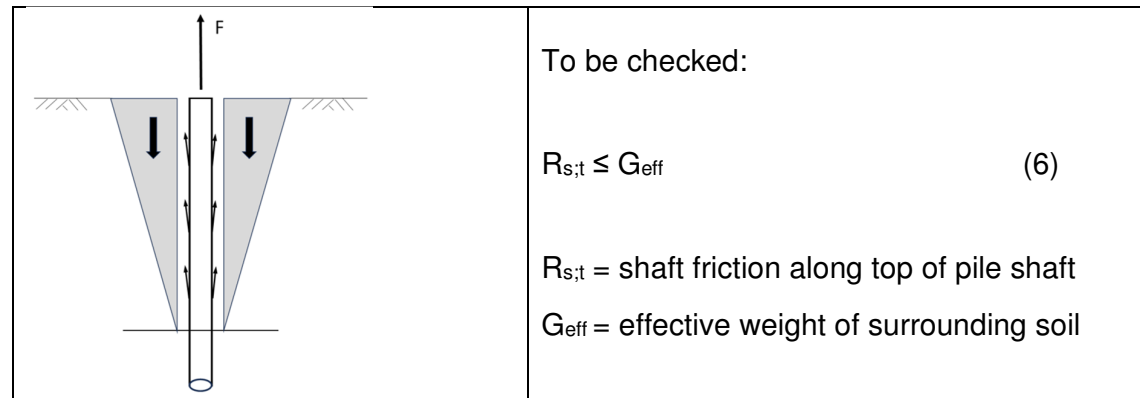


Figure 6. Limitation of the shaft friction along top part of pile shaft.

This risk is particularly relevant for anchor piles, which, due to their relatively low axial stiffness, tend to transfer tensile forces to the surrounding soil mainly along the upper portion of the pile shaft.

Currently, there is no standardized calculation rule to account for the shaft friction shortfall caused by a low effective stress level in the adjacent soil layer when determining the tensile capacity of (anchor) piles. Therefore, a more pragmatic approach has been adopted:

- For tension-loaded anchor piles, no shaft friction may be calculated up to a depth where the effective vertical stress level reaches at least 50 kPa (SLS value), unless it is computationally demonstrated that a higher initial level is permissible.

Restricting shaft friction calculations to start only at the level where the effective vertical stress reaches at least 50 kN/m² is a realistic, yet still simplified, approach to the actual situation. However, caution remains necessary, and in case of following option 1 of the design approach as described earlier, consideration should already be given to the execution of suitability tests during the design phase of the anchor piles.

This is particularly important in cases of:

- significant variations in cone penetration test (CPT) results within a pile field;
- combined $(\alpha_t \cdot \phi_s) > 4.0$;
- dense to very dense sand with CPT-values $q_c > 20$ MPa.

In such situations, it is advisable to conduct a detailed simulation of the suitability tests with the assistance of an experienced geotechnical consultant.

Load-Displacement Behaviour of Tension-Loaded Anchorpiles

Design calculations are also proposed for the axial spring stiffness of the piles. Anchorpiles are relatively sensitive to extending in comparison with other tension piles such as prefabricated concrete piles, steel tubular piles and grouted piles using steel H-beams. When using anchor piles, the axial spring stiffness will have an important effect on the load distribution and distortion of the construction being supported, as is usually the case with for example underwater concrete floors.

Anchorpiles differ from more traditional foundation piles primarily due to their relatively flexible axial load-displacement behaviour. When anchorpiles are subjected to tension, the grout sheath must generally be considered cracked over a large portion of the pile length, meaning that in effect only the anchor steel determines the axial stiffness.

A relatively low axial spring stiffness can significantly affect the force distribution in the structure transferring loads onto the anchor piles, especially when other nearby foundation elements exhibit a much higher axial spring stiffness.

Less commonly known is that, for relatively flexible anchorpiles, the amount of anchor steel also has a major influence on the force transfer along the length of the pile itself and, consequently, on the geotechnical tensile load-bearing capacity. This may seem counterintuitive since, in traditional foundation piles, calculation rules do not establish any correlation between geotechnical tensile capacity and the axial stiffness of the pile itself.

The design capacity of a single, constantly tension-loaded pile—assuming the effective soil mass is not the governing factor—depends according to the Dutch design rules on the pile diameter, the pile friction factor (at the grout-sand interface), the measured cone resistance q_c of a Cone Penetration Test (CPT) (corrected for the reduction of effective stress due to lowering ground level or excavation of the construction pit during loading of the anchor piles if applicable), and the pile bond length within the load-bearing sand layer.

So how does this actually work? To understand this, it is necessary to examine in more detail how skin friction develops along the pile shaft within the load-bearing sand layer. This can be done by dividing the pile shaft into multiple segments connected in series. For each segment, the relationship between the displacement of that segment along the adjacent sand particles is crucial. See Figure 7 below.

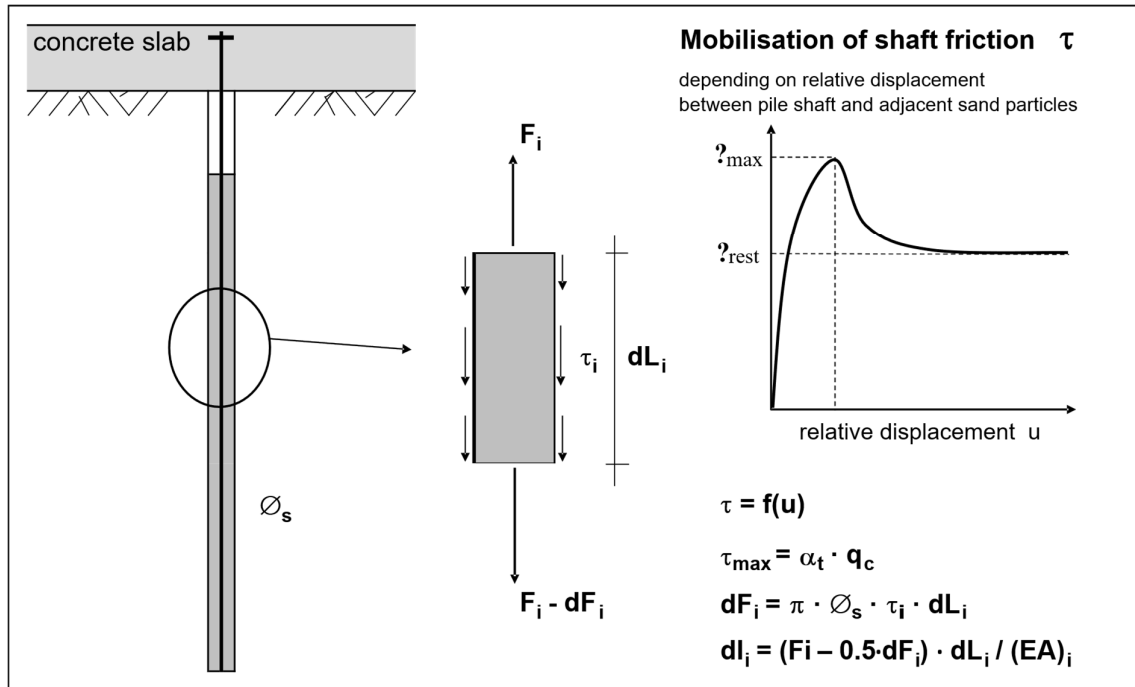


Figure 7. Development of skin friction with respect to displacement.

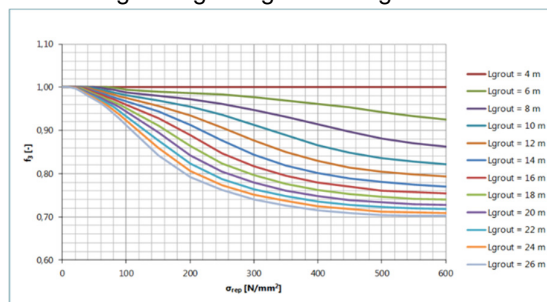
By connecting all these individual segments in series along the pile length, the expected pile head displacement can be determined for a given tensile load at the pile head. This approach has been introduced to realistically assess the load-displacement behaviour and, consequently, the axial spring stiffness under tension.

This calculation model can also be applied in the context of predicting the load-displacement behaviour for production piles during suitability tests as advised earlier.

For calculation of the shaft friction under tension, the influence as result of the theoretical model as described above is schematized as per design-lines in figure 8 below, representing the reduction factor or efficiency factor f_3 in equation (2).

Distinction is made for anchor piles where the grout body, or grouted bond length, is pressure-grouted or made under more or less hydrostatic pressures. See previous table 1 for anchorpiles types A and B, and C, D and E respectively.

Pressure grouting along bond length



Hydrostatic grouting along bond length

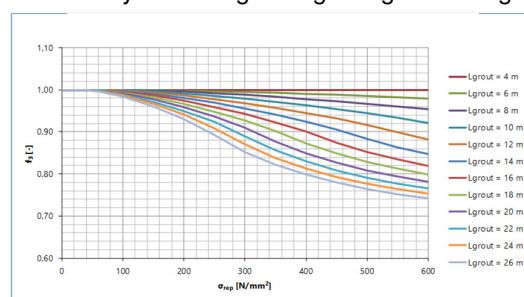


Figure 8. Reduction factor f_3 related to efficiency of shaft friction under tension.

Force Distribution along the length of the Anchorpile

The calculation model used to determine load-rise behaviour, as described previously (also see figure 7), can also be applied to gain insight into the force transfer along the pile shaft. It also allows for limiting shaft friction along the upper part of the pile shaft if the adjacent sand layer, due to its still (too) low effective stress level, is unable to absorb the tensile load from the pile.

The influence of both axial stiffness and the need to limit shaft friction can best be illustrated through a calculation example. The anchor piles function as tension elements in a dry excavation pit with underwater concrete, see Figure 9.

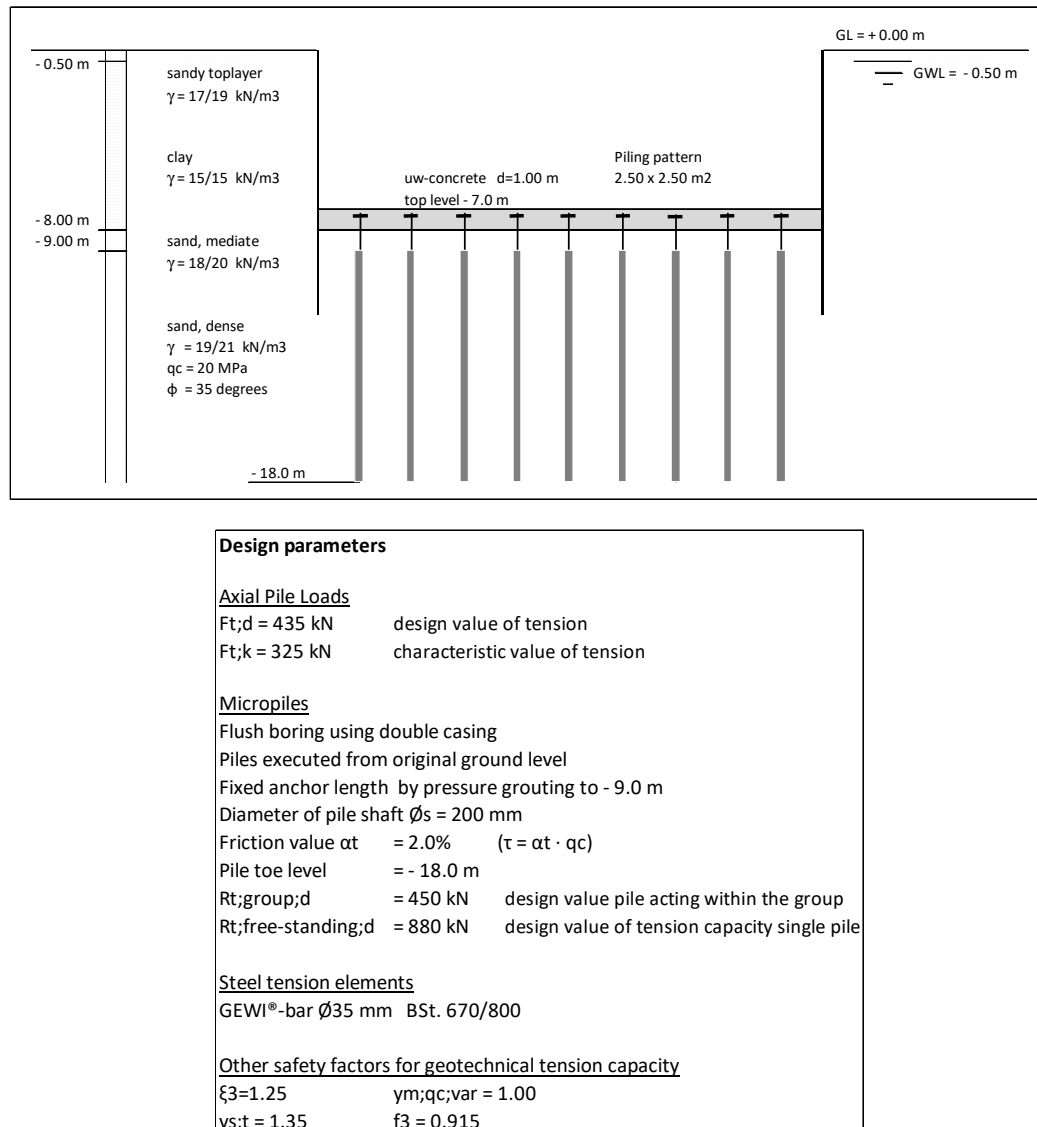


Figure 9. Calculation example construction pit with underwater concrete slab.

In a simplified scenario with a uniformly assumed sand layer, the same anchorpile is analysed for four different conditions: two variants—one with an infinitely high and another with a relatively low axial stiffness—followed by both variants analysed with

and without limiting shaft friction along the upper part of the pile. See Figure 10 for the calculated load distribution along the pile shaft.

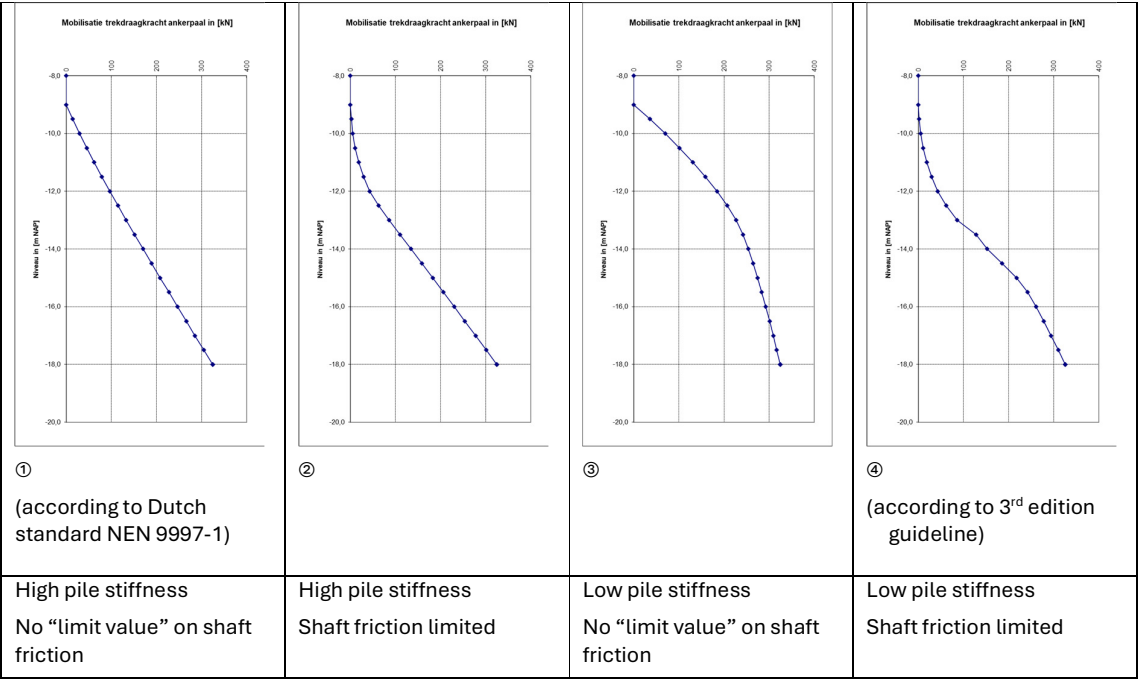


Figure 10. Calculated load distribution along the pile shaft.

From figure 10, the characteristic differences in friction resistance distribution and the mobilization of tensile capacity are clearly visible. In the flexible variant (③), the frictional resistance initially tends to develop along the upper section of the pile shaft, unlike in the stiff variant (①). However, due to the low effective stress level at this depth, force transfer is not possible, as seen in the more realistic distribution of the flexible variant (④). Additionally, variant (②) shows that in the case of a stiff foundation pile, significantly less load transfer occurs along the upper shaft than expected.

In this calculation example, the influence of the limitation on mobilized friction resistance extends to approximately 5 to 6 meters below the excavation level. However, the critical factor is not the depth itself but the effective stress level required to mitigate this unfavourable effect. Similar analyses of other cases with load-bearing sand layers near the excavation level, show a recurring pattern. If (anchor) piles are considered as single piles rather than part of a pile group, this characteristic force distribution becomes even more pronounced due to the absence of damping effects from group behaviour.

Additionally, increasing deformation of the anchor pile leads to a drop in available shaft friction (softening) after exceeding the peak mobilized friction resistance, as illustrated in Figure 4. This effect primarily occurs along the upper portion of the pile shaft, where elongations are the greatest. However, during suitability tests, as tensile load increases and elongation increases, this effect may extend to greater depths. Consequently, the ultimate tensile capacity of an (anchor) pile may be lower than predicted by standardized calculation rules.

In the calculation rules for determining the geotechnical tensile capacity according to the Anchorpile Guideline, both influences are accounted for using the reduction factor f_3 to reflect the so-called length effect also known as “efficiency factor”. The value of f_3 is determined in the design phase based on the characteristic tensile load from the structure at the anchor pile head. However, during suitability tests, the applied tensile force can reach 1.5 to 2 times (or even higher) the design tensile load. In other words, the test load puts a much larger demand on the length effect, than the original pile design anticipates.

In the normal service condition of anchor piles, the primary concern is the possible low effective stress level. However, during suitability tests, the softening effect plays a more significant role. The unfavourable influences of the low effective stress level in the upper layers of the load-bearing sand layer, as well as the reduction in frictional resistance due to softening, results in a significantly lower ultimate shaft friction under tension than expected according to standardized calculation rules.

PILE TESTING

Investigation Tests on Sacrificial Anchorpiles

It is strongly recommended to conduct investigation tests on the proposed type of anchorpile before starting a project. This allows for a better understanding of the expected friction properties between the pile shaft and the surrounding load-bearing soil layers. These properties are highly dependent on the type of anchorpile and its installation method.

Additionally, for each individual load-bearing soil layer, key factors include:

- shape (round, angular);
- particle fraction (coarse, fine);
- relative density;
- possible admixture with cohesive components.

For special soil conditions in the Netherlands, such as marl, glauconite-bearing sand, or over consolidated clay and loam layers, investigation tests are mandatory.

Beyond the aspect of test loading and analysing results, the registration of the execution process of trial piles is also crucial.

Conducting investigation tests also confirms the suitability of the selected anchor pile type for the given soil conditions. While significant experience has already been gained in most cases, drilling depths continue to increase, and new developments in drilling processes and equipment continue to emerge.

Investigation tests are always performed with tensile loads, using a stacked reaction structure to easily transfer the mobilized reaction force to the surface.



Figure 11. Investigation test.

Even before the first edition of the Dutch Guideline (2011) was published, investigation tests were being conducted. However, after its release, a more structured and uniform approach was established—not only for test execution but also for the analysis of results and determination of the pile friction factor (α_t). Over the years, this has led to a number of lessons learned, revealing clear trends in the expected results for different anchor pile types under various conditions.

As an example figure 12 shows the results of investigation tests on anchorpiles type B (flush-drilling with single casing and pressurized grouting of the bond length) in different sand layers loading the piles to geotechnical failure. It presents a collection of test results by several specialist piling contractors, as obtained from different projects throughout The Netherlands during the past 20 years. Test results for anchorpiles A, C, D and E (see table 1) can be found in the Guideline.

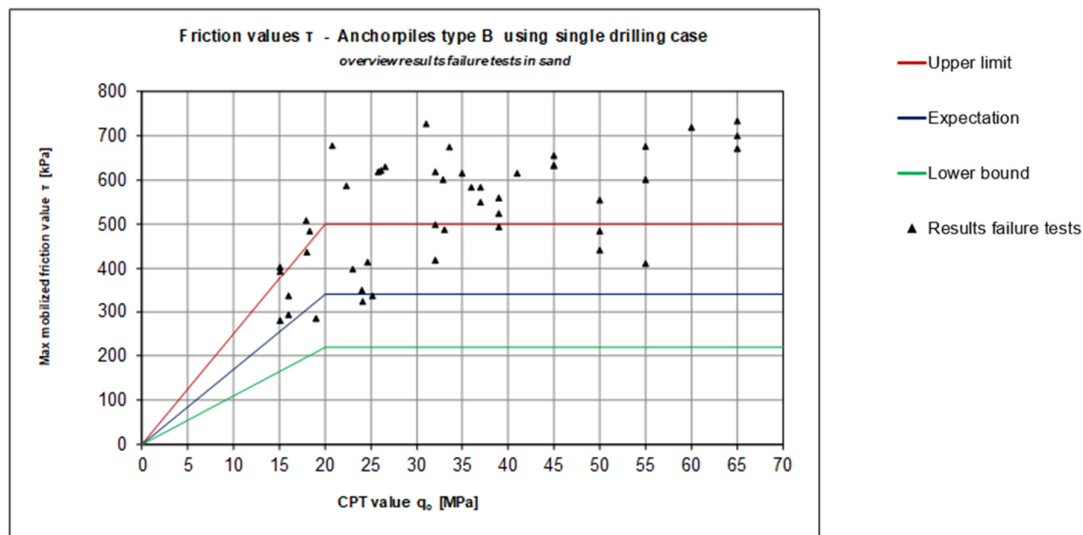


Figure 12. Results of investigation test on anchorpiles type B.

Suitability Tests on Production Piles

If the pile design is based on high optimized values of the friction factor α_t derived from the investigation test on site previously (design approach option 1 as explained earlier), at least 3% of the total number of production piles have to be tested. This is to verify the basis of design, the in-situ geotechnical bearing capacity and the load-displacement behaviour.



Figure 14. Suitability test conducted from pontoon after wet excavation of the construction pit.

Suitability test are always tension-loaded, as nine out of ten times tension capacity is governing during its life span. But even when compression is governing, due to the pile slenderness (and therefore almost certain risk of buckling), from a practical point of view it's "impossible" to conduct these tests under a downward force.

Determining the correct value of the maximum test load is critical, and it can be seen as a sort of balancing act:

- the maximum test load must be high enough to prove sufficient bearing capacity;
- but the test load must certainly be not too high to prevent unnecessary overloading or even pulling out.

For instance, not following the geotechnical design rules as per the guideline, things can and will go terribly wrong when the guideline is mis-interpreted or not used at all.

The best way to illustrate this is with the following calculation example.

Example of wrong pile design neglecting the advice as per Guideline

In this example the geotechnical bearing capacity (and thus installation level) was based on the design rules as per Dutch Geotechnical Code NEN 9997-1 allowing full (theoretical) shaft friction to be calculated from NAP -9.0 m, which is just only 1.0 m below excavation level within the construction pit.

With reference to the situation as shown in figure 9, without going into all specific design-details involved, the design lead to the following key results:

- installation level: NAP -18.0 m
- pile bearing capacity (tension) as part of a group: $R_{t;group;d} = 450 \text{ kN}$ (*) (**)
- pile bearing capacity (tension) as standalone pile: $R_{t;standalone;d} = 880 \text{ kN}$ (*) (**)
- maximum test load to be applied in suitability tests: $100\% F_p = 850 \text{ kN}$

(*) *In this case with assumed full shaft friction calculated from 1.0 m below excavation level, pile bearing capacity as part of a group with rather small centre-to-centre distances, is substantially influenced (reduced) by the so called group-effect; see reduction factor f_2 in equation (2). Therefore the bearing capacity of the same pile but than as a standalone pile (with $ctc=\infty$) is (theoretically) much higher than as part of the pile group. For understanding of the so called group-effect, see references [1] and [3].*

(**) *Design values.*

Assuming the use of a GEWI®-bar $\varnothing 43 \text{ mm}$ BSt.670/800 capable to carry the test load, the simulation of the suitability test (now correctly taking into account all design-details and advice as per the Guideline Anchorpiles) produces the following simulation for the load-displacement behaviour:

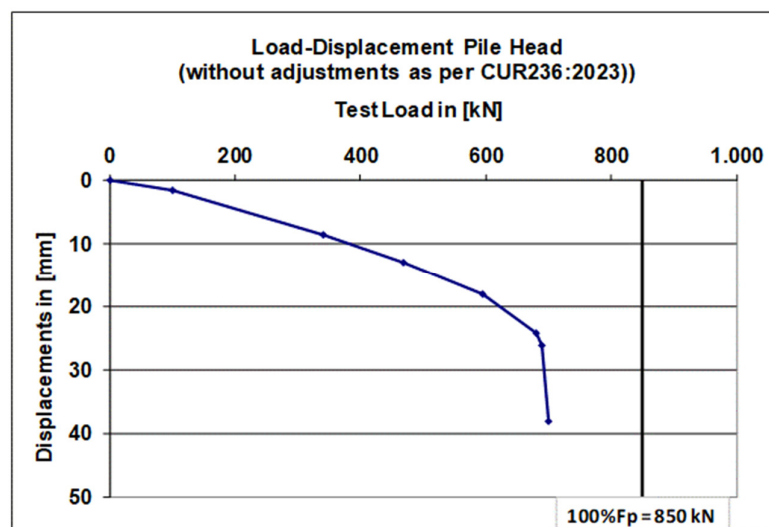


Figure 15. Simulation of the load-displacement during a suitability test (in case pile design is not in accordance with the Guideline).

This design, not taking into account the limitation of the shaft friction along the upper part of the pile shaft (see figure 6) leads to a much too high not realistically estimated bearing capacity and therefore a much too high maximum test load.

Consequence is a geotechnical overloading of the anchor pile to be tested, resulting in premature geotechnical failure.

In such a situation, it is therefore not a case of a poorly executed anchorpile although this is often (incorrectly) concluded.

The present question is how this failure could have been avoided. This can be best illustrated by recalculating the previous example, but now following the guideline and neglecting the shaft friction to a level at NAP -13.0 m (where $\sigma'_{v;k} = 54 \text{ kN/m}^2$, thus $\geq 50 \text{ kN/m}^2$) as explained earlier.

The revised pile design results in:

- installation level: NAP -19.0 m
- pile bearing capacity (tension) as part of a group: $R_{t;group;d} = 460 \text{ kN}$ (*) (**)
- pile bearing capacity (tension) as standalone pile: $R_{t;standalone;d} = 700 \text{ kN}$ (*) (**)
- maximum test load to be applied in suitability tests: $100\% F_p = 650 \text{ kN}$

(*) See for explanation previous page.

Calculation of the shaft friction starting at this lower level of NAP -13.0 m instead of NAP -9.0 m results in less reduction due to the group-effect, as well as a lower bearing capacity as a standalone pile without this group-effect. Consequently the maximum test load will be more realistic and significantly lower.

(**) Design values.

Simulation of the suitability test for this revised situation, incorporating these adjustments, now results in:

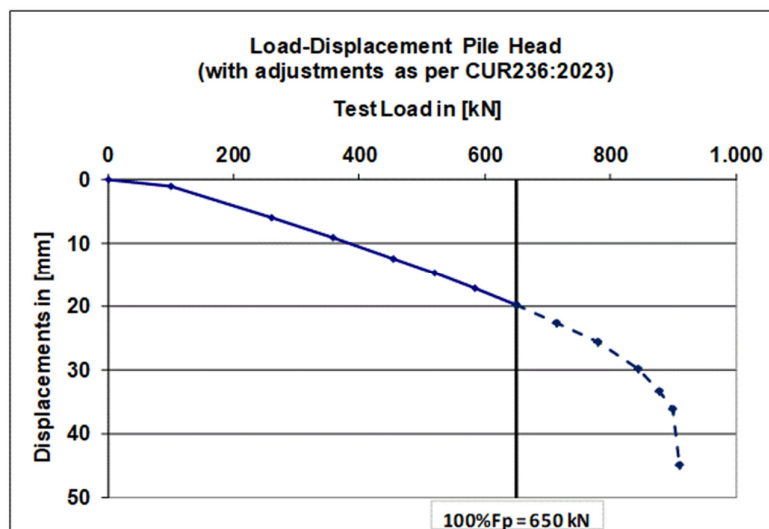


Figure 16. Simulation of the load-displacement during a suitability test (in case pile design is in accordance with the Guideline).

It is clearly visible that the combination of neglecting the friction of the top 5.0 m along the pile shaft and the 1.0 meter deeper pile installation level restores the overall safety and reduces the required test load to a more realistic level. This significantly reduces the unnecessary risk of pulling out anchorpiles during testing.

The previous analysis pointing at the importance of limiting the shaft friction along the top part of tension-loaded (anchor)piles is not just a theoretical case, but has unfortunately led to the actual pulling out of anchorpiles in practice before. This underlines the importance of the CROW-CUR Report 236:2023 – Guideline Anchorpiles.

STATE OF THE ART OF ANCHORPILES IN DUTCH INFRASTRUCTURE

The guideline has proven its value in daily practice. Especially in large infra structural works as the recently completed Maasdelatunnel near Rotterdam, where over 9,000 anchorpiles have been successfully installed and tested. At the deepest points at the ends of the north and south ramp, depth of the wet excavation reached a level of almost 35 meter below ground level. Anchorpiles were applied to prevent the uplift of the underwater concrete slabs subjected with about 25 to 30 m of upward water pressure.

Worth mentioning is:

- the vertical drilling of anchorpiles both flush drilled with single casing (type B) and self-drilling (type C) to almost 70 m below ground level;
- installation of both GEWI® bars $\varnothing$ 75 mm BSt. 670/800 and tubular sections $\varnothing$ 101.6x25.0 mm E470+;
- tight time schedule leading to having approximately 12 to 14 nos. of drilling rigs at the same time (6-7 south ramp and 6-7 north ramp) and operating at close distance from each other;
- extensive supervision and quality control during piling;
- testing with loads up to 2,750 kN (from pontoon).

MISCELLANEOUS

In the context of this paper it's impossible to describe all items that are part of the Guideline Anchorpiles. Nevertheless the following aspects are at least worth mentioning briefly:

Structural steel elements

To prevent the use of brittle or corrosion sensitive steel elements, specific demands are put to the properties of the massive bars and tubular sections which are commonly installed in the anchor piles. The guideline also provides recommendations for corrosion protection. Here, measures depend on the envisaged life span and also on the aggressiveness of the soil layers and the groundwater in which the anchorpiles are placed.

Design rules for fatigue are in line with the Eurocode 2 (concrete structures) and Eurocode 3 (Steel structures).

A new calculation rule for determining buckling stability in compression-loaded anchorpiles, is also part of the guideline. It's important to note that in many cases, where anchorpiles are applied under shallow ramps of traffic roads and penetrating soft to very soft ground layers (such as peat), buckling can be governing for the dimensions of the steel element to be used or even decisive for choosing the wright and most suitable type of anchorpile.

Supervision, quality assurance and quality control

The last, but certainly not the least important part of the guideline, is supervision and quality assurance.

As anchorpiles are sensitive for the way they are executed, it's essential to have a clear overview of how each pile is made. Especially in case of following design approach option 1, using high optimized values for the calculation of the shaft friction of anchorpiles. Since only 3% of all production piles are subjected to in-situ suitability test, good insight and expert judgement on the key success factors of the piling is essential. Where unfavourable deviation is noticed, it is important to analyse this more in detail or even to test these piles in addition to the other piles already tested. Comparison of the load-displacement of these piles can be a reason to approve these piles or to replace piles having doubt of t's quality.

CONCLUSION

After 25 to 30 years of experiences and since the publication of the first edition of the guideline in 2011, anchorpiles are frequently and successfully applied in small projects and large scale infrastructural projects throughout The Netherlands. The comprehensive framework as per Dutch "Guideline for Anchorpiles" has become indispensable, providing the necessary information to achieve an optimum design and reliable execution of these piles.

Daily use, new insights and expanding dimensions of structures, will undoubtedly lead to further developments and improvements of anchorpiles, it's design, pile execution and complex testing. So pressure on craftsmanship, structured collecting of experiences and creativity will remain, even in times where AI seems to take things over.

In the years to follow, new insights will quickly emerge and further improvements and adjustments will be necessary. So it can be expected that within a couple of years there will be again a revised (4th) version of the Guideline for Anchorpiles, which is a good development to retain the collected knowledge and to bring it to even higher levels.

REFERENCES

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- [2] CROW-CUR Report 236:2023 – Anchor Piles Guideline, 3rd Revised Edition
- [3] CUR Report 2001-4 Design rules for Tension Piles, 2nd Edition; 2003