Proceedings of the XVII ECSMGE-2019
Geotechnical Engineering foundation of the future
ISBN 978-9935-9436-1-3

doi: 10.32075/17ECSMGE-2019-0272

XVII European Conference
ECSMGE 2019
Reykjavik
on Soil Mechanics
and Geotechnical Engineering

Spinnanker – Technical developments of an innovative foundation and anchor system

Spinnanker – Développements techniques d'un système de fondation et d'ancrage innovatif

R. Katzenbach, S. Rochée
Technische Universität Darmstadt, Institute and Laboratory of Geotechnics, Darmstadt, Germany

S. Leppla
Ingenieursozietät Professor Dr.-Ing. Katzenbach GmbH, Frankfurt am Main, Germany

P. Okonek, L. Guerra
Spinnanker GmbH, Vienna, Austria

ABSTRACT: The Spinnanker is a new type of foundation and anchor system which can be installed easily in cohesive and non-cohesive soils without heavy technical equipment. The system consists of up to 12 threaded bars with a length of up to 8 meters which are screwed in the subsoil. A round steel plate assures the load transfer from the construction to the threaded bars. In the meantime, more than 8000 Spinnanker have been installed worldwide with a wide range of applications e.g. foundations for steel halls or anchor point for guyded masts. Spinnankers are especially suitable for a temporary use as they can be completely removed without heavy technical equipment. The Spinnanker has been continually developed on the basis of extensive investigations and practical experience gained on the field. Particularly, extensive analyses of the load-deformation behavior have been performed in order to get an economic and safe design for each situation. In this paper, the authors give a scientific review of the technical development and an outcome of future developments of this innovative type of foundation and anchor system, with details on field investigations recently performed and a particular selection of application examples.

RÉSUMÉ: Le Spinnanker est un nouveau type de fondation et d'ancrage qui peut être monté facilement autant dans des sols cohésifs que pulvérulents sans nécessiter d'équipement technique lourd ou encombrant. Le système est composé de 6 à 12 tiges filetées avec une longueur variant jusqu'à 8 m et vissées dans le sol à travers une plaque circulaire assurant le transfert des charges vers la structure. Jusqu'à présent, plus de 8000 Spinnanker ont été montées dans le monde avec un panel d'applications varié, par exemple pour des fondations de bâtiments en acier ou des ancrages d'haubans pour des mâts et pylones. Le Spinnanker est particulièrement adapté pour une utilisation temporaire du fait qu'il est très facilement démontable sans laisser de trace. Des études expérimentales approfondies et l'expérience gagnée sur le terrain ont permis d'assurer continuellement le développement technique de ce système. Des études approfondies du comportement en déformation sous charge ont en particulier été menées afin d'obtenir une conception économique et sécuritaire. Les auteurs donnent dans cet article un bref aperçu des développements techniques récents de ce système de fondation et d'ancrage innovant en s'appuyant sur des essais réalisés sur le terrain et une sélection de cas pratiques.

Keywords: Spinnanker, foundation, anchor, field tests

1 AN INNOVATIVE FOUNDATION AND ANCHOR SYSTEM

The Spinnanker is a new type of foundation and anchor system consisting in threaded steel bars which are screwed in the subsoil. It can be installed easily by using an handheld turning machine in cohesive and non-cohesive soils.

The most widespreaded model has 6 to 12 high-strength threaded bars with a 900/1100 steel quality, a nominal diameter of 15 mm and a length from 2,0 m to 6,0 m, in particular cases up to 8,0 m. The threaded bars are screwed in the subsoil with an angle of 30 or 45° through a circular plate which is protected against corrosion. The mounting plate fixed above the ground plate can be levelled. The designation for this model comprises the number of bars, their length and their nominal diameter (Figure 1).

Figure 1. Spinnanker XII / 2.0 / 15 (this Spinnanker comprises 12 threaded bars with a length of 2.0 m and a nominal diameter of 15 mm) - (Product prospect Spinnanker)

This model has been successfully installed worldwide in very different types of soils including soft marine clays in North Germany, desert sand in Abu Dhabi (UAE), compacted gravel or also dense ice of glaciers in alpine areas (Figures 2 and 3). It is possible to combine Spinnankers at a given foundation or anchor point in order to increase the load bearing capacity (Figure 4). In case presented on Figure 5, precast concrete has been additionnally used for a simplified installation procedure.

Figure 2. In situ load test for a mobile phone tower in Abu Dhabi, UAE (2014)

Figure 3.Horizontal pull out test of a Spinnanker VI / 3.0 / 15 on a glacier in Zell am See, Austria (2009)

Figure 4. Combination of Spinnankers for anchoring guy wires of temporary line towers, Austria (2018)

Figure 5. Hybrid foundation of precast concrete and Spinnankers for a climb parc in Spain

Further custom made models are possible by varying the inclination of the bars or their diameter, for example 18, 20 or 26 mm. It is also possible to adapt the geometry of the plate and the position of the rods in order to optimize the load-bearing capacity of the system for a given application. For example, a new model is currently developed and tested for constructions in downtown areas (Rochée 2018). In this case, the bars are screwed up to a maximal depth of 50 cm under the ground surface in order to avoid collisions with lines and to simplify the construction permit. The form of the plate and the position of the bars (Figure 6) have been adapted for holding the given bending moments.

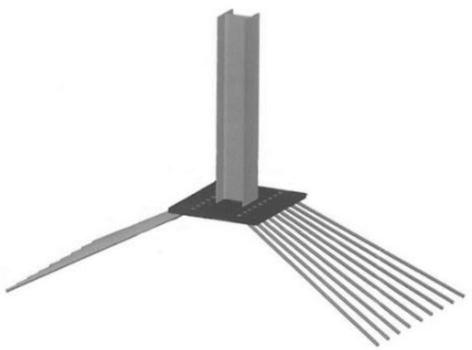

Figure 6. Design of a new model for an application in downtown areas

Main advantages of Spinnanker are:

- The foundation and anchor points are quickly installed and immediatly load-bearing;
- The installation can be done in narrow and sloped areas with difficult access, as there is no need of heavy equipment or construction machine;
- The system can be removed completely without damaging the ground and can also be reused.

Spinnankers are therefore very well adapted for a temporary and semi-permanent use. For a long term use, the corrosion rate of the threaded bars must be taken into account, as defined in the EAU (2012).

The list of projects in which Spinnankers have been installed is characterized by a wide range of application with some examples listed below:

- Anchor points for guy ropes of guyed masts or for assuring the stability of forestry and construction machines,
- Anchoring of protection walls and barriers,
- Anchoring of avalanche protection systems,
- Foundations for prefabricated modular homes or steel halls,
- Foundations for photovoltaic systems.

2 DESIGN AND INSTALLATION PROCEDURE

2.1 Procedure step by step

The process from the definition to the completion of a project realised with Spinnankers is divided in following steps:

- **Preliminary design**, i.e. the choice of an adapted system of Spinnankers, based on the results of the ground investigations and of the given workloads on the future construction;
- **Suitability tests**, in order to evaluate the load bearing capactiy of the selected Spinnankers on the project field and compare it with the load bearing capacity considered in the preliminary design;
- **Dimensioning** including the calculations and the realisation of a Spinnanker plan;
- **Installation** of all Spinnankers according the plan with detailed documentation of the installation process;
- **Acceptance tests** for at less 10 % of the installed Spinnankers.

2.2 Preliminary design

Adapted Spinnankers are selected under specification of the workloads on the construction and of the subsoil conditions. The exploration depth of the ground investigations should cover all layers which are significantly influenced by the construction as well as hydrogeologic conditions.

A first design concept has been developed for the most widespreaded model presented in part 1. For this purpose, more than 60 strain-controlled tests have been performed in 2009 with different load inclinations and in different soil types in the framework of a research project. The design charts given in (Mayrhofer et al. 2010, Katzenbach & Leppla 2011) can be used for vertical axial loads on the Spinnankers.

The database used for the preliminary design has been ever since regularly extended considering the large number of load tests performed in practice and the experience gained on the field. Consequently, the procedures for testing and result analysis have also been adapted, as shown in the next part.

2.3 Evaluation of the load bearing capacity

After the preliminary design, the load bearing capacity of the Spinnankers is evaluated on the project field by means of suitability tests. In most cases, vertical pull out tests are performed.

The testing apparatus for the vertical pull out tests with a maximal load capacity of 200 kN is shown on Figure 7. The vertical load is applied in increments by means of an hydraulic cylinder. The applied load, the vertical displacements and the time are measured. The measured value of the bearing capacity $R_{t,m}$ (kN) of the Spinnankers under a vertical pull out load is evaluated using the load-displacement curve.

The calculation of the characteristic value $R_{t,k}$ (kN) of the load bearing capacity takes into account the number of load tests:

$$R_{t,k} = MIN\left\{\frac{(R_{t,m})_{mean}}{\xi_1};\frac{(R_{t,m})_{min}}{\xi_2}\right\} \qquad (1)$$

Where $(R_{t,m})_{mean}$ (kN) and $(R_{t,m})_{min}$ (kN) are respectively the mean value and the minimum value of the load tests performed on the same project field under the same conditions. The values of the correlation factors ξ_1 and ξ_2 are set

Figure 7. Testing apparatus for vertical pull out tests

according the table A.9 from appendix A of DIN EN 1997-1:2014-03 and depend directly of the number of tests.

The characteristic value of the bearing capacity $R_{t,k}(\vartheta, n_{Sp})$ (kN) for an inclined load and/or for a group of multiple Spinnankers is then estimated using correction factors k_ϑ (-) and k_n (-):

$$R_{t,k}(\vartheta, n_{Sp}) = R_{t,k} \cdot k_\vartheta \cdot k_n \qquad (2)$$

ϑ (°) and n_{Sp} (-) correspond here respectively to the inclination of the load towards the horizontal axis and the number of combined Spinnankers.

The correction factor k_ϑ (-) used for the estimation of the load bearing capacity of a Spinnanker under an inclined load is calculated as follows:

$$k_\vartheta = \sqrt{\frac{a^2 \cdot b^2}{a^2 \cdot (tan\vartheta)^2 + b^2} \cdot (1 + (tan\vartheta)^2)} \qquad (3)$$

In this equation, the parameter a (-) depends of the soil type and varies between 0.50 and 1.0. The parameter b (-) depends of the direction of the load with b = 1.00 for a pull out force (0 ° ≤ ϑ ≤ 90 °) and b = 1.15 for a compressive force (-90 ° ≤ ϑ ≤ 0 °). The correction factor k_ϑ is represented in function of the load inclination in case of a = 0.50 on Figure 8.

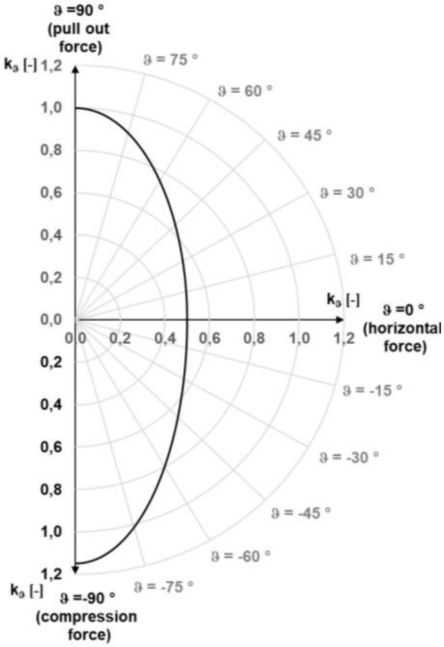

Figure 8. Correction factor in function of the load inclination (with a = 0.50)

The correction factor k_n (-) is used if multiple Spinnankers are combined on a foundation or anchor point and is calculated as follows:

$$k_n = p \cdot n_{Sp}{}^{z} \tag{4}$$

Where the parameters p (-) and z (-) depends on the number n_{Sp} (-) of combined Spinnankers:

- for $2 \leq n_{Sp} \leq 5$: $p = 0.90$ and $z = 1.0$;
- for $n_{Sp} > 5$: $p = 0.95$ and $z = 0.964$.

2.4 Design according Eurocode 7

For the ultimate limit state, the design actions $E_{d,\vartheta}$ (kN) which corresponds to a resulting force in the direction ϑ (°) are compared with the design resistance $R_{d,\vartheta}$ (kN) in the same direction:

$$E_{d,\vartheta} \leq R_{d,\vartheta} \tag{5}$$

The design values of actions and resistances are calculated using partial safety factors, as given in Equations (6) and (7). The values of the partial factors according DIN EN 1997-1 and used in the procedure described in this article are given in Table 1.

$$E_{d,\vartheta} = \gamma_G \cdot E_{G,k} + \gamma_Q \cdot E_{Q,k} \tag{6}$$

$$R_{d,\vartheta} = \frac{R_{t,k}(\vartheta, n_{Sp})}{\gamma_{s,t}} = \frac{R_{t,k}}{\gamma_{s,t}} \cdot k_\vartheta \cdot k_n \tag{7}$$

Table 1. Partial safety factors for computing design actions and resistance

Parameter		**Value**
Unfavourable permanent actions	γ_G	1.35
Favourable permanent actions	γ_G	1.00
Unfavourable variable actions	γ_Q	1.50
Favourable variable actions	γ_Q	0.00
Pull out resistance (tension load tests)	$\gamma_{s,t}$	1.15
Pull out resistance (experiences)	$\gamma_{s,t}$	1.50

3 CASE EXAMPLES

3.1 Case example 1: Anchoring for overhead line tower with extra high voltage transmision (EHV) 380 kV in Rommerskirchen (Germany)

3.1.1 Design actions and subsoil conditions

In this case, the Spinnanker is used as anchor point for guy ropes. The characteristic value of the resulting force $E_{G,k}$ in the direction $\vartheta = 30$ ° is 144 kN. The design value of the actions is obtained as follows:

$$E_{d,\vartheta} = E_{G,k} \cdot \gamma_G = 144 \cdot 1.35 = 194\ kN \tag{8}$$

Soil data includes a soil profile up to 7.0 m and the results of a dynamic probing at the mast location. The subsoil consists at first of native soil and a silt layer up to 1.1 m and then of a silty sand from 1.1 m to 7.0 m. A mean friction angle of $\varphi'_k = 29$ ° and a mean soil weight of $\gamma'_k = 12.0$ to 12.5 kN/m³ have been used for the preliminary design.

3.1.2 Pull out tests and safety design

The suitability tests are performed on Spinnankers of type XII with a rod length of 6.0 m, which should be the mostly used type for the anchor points. This choice is based on the soil parameters given above and the minimum test load estimated as follows. In agreement with the expert inspector, vertical pull out tests have been performed on two Spinnankers until reaching the ultimate limit state. Considering a combination of 4 Spinnankers (Figure 9), the minimum test load for verifying the adopted characteristic resistance (EA Pfähle 2012) is:

$$\begin{aligned} P_p &= E_{d,\vartheta} \cdot \gamma_{s,t} \cdot \xi_1 \cdot \frac{1}{k_n \cdot k_{\vartheta=30°}} \\ &= 194 \cdot 1.15 \cdot 1.3 \cdot \frac{1}{(0.9 \cdot 4) \cdot 0.555} \\ &\approx 150\ kN \end{aligned} \tag{9}$$

During the tests, the load is applied without preloading and incrementally as given in Table 2. For each load step, the head displacement is measured with a dial gauge every 3 minutes and plotted in function of the time. The time-displacement and load-displacement curves are interpreted according an internal procedure (Guerra 2017).

Figure 9. Anchoring with 4 Spinnankers (Type XII / 6,0 / 15)

Table 2. Load steps for the vertical pull out tests

Load step Nr.	0	1	2	3	4	5
Load [% Pp]	0	27	53	67	73	80
Load [kN]	0	40	80	100	110	120

Load step Nr.	6	7	8	9	10
Load [% Pp]	40	0	80	100	
Load [kN]	60	0	120	150	Max. 190

Table 3. Bearing capacity from the two tests

	Test 1	Test 2
Measured bearing capacity $R_{t,m}$	148 kN	146 kN
Corresponding head displacement	5.6 mm	6.2 mm

The calculated bearing capacity and the corresponding head displacement are given in Table 3. Assuming $(R_{t,m})_{mean} = 147\ kN$, the design resistance is estimated using Equations (1) to (4) and Equation (7) and then compared with $E_{d,\vartheta}$ using Equation (5):

$$R_{d,\vartheta} = \frac{(R_{t,m})_{mean} \cdot k_\vartheta \cdot k_n}{\xi_1 \cdot \gamma_{s,t}} = 196\ kN \tag{10}$$

3.2 Case example 2: Foundation for a steel hall (fish plant) in Schelklingen (Germany)

3.2.1 Design action and subsoil description

The steel hall for which Spinnankers are used as foundation is represented on Figure 10.

Figure 10. Steel hall founded on Spinnankers

The permanent and variable actions lead to a vertical compression force (ϑ = -90°) with a design value of $E_{d,\vartheta} = 311\ kN$.

According to the soil profile, the subsoil consists up to 3.90 m mostly of silt with little amounts of sand and gravel. Above this depth, a layer of gravel with silt and sand is given. A mean friction angle of $\varphi'_k = 27°$ and a mean soil weight of γ'_k = 13.0 to 13.5 kN/m³ have been estimated.

3.2.2 Compression test and safety design

A vertical compression test (Figure 11) until reaching the load bearing capacity has been performed on a Spinnanker of type XII with a rod length of 8.0 meters, which should be used for the foundation. Considering the subsoil conditions, a bearing capacity of 287 kN is assumed for this Spinnanker type. The minimum test load P_p has been evaluated to 278 kN using Equation 8 with the following parameters: $\xi_1 = 1.4$ (one test performed), $k_n = 2 \cdot 0.9 = 1.8$ (combination of 2 Spinnankers), $k_\vartheta = 1.0$ (considering a vertical compression test) and $\gamma_{s,t} = 1.15$ on the safe side.

Figure 11. Vertical compression test

In this case, three load steps of 150 kN, 250 kN and 300 kN without preloading have been applied. Head displacements are measured with an optical level 25 minutes after applying the constant load. The analysis of the load-displacement curve according the internal procedure in (Guerra 2017) leads to a bearing capacity of 281 kN which is obtained for a head displacement of 10.3 mm.

The results are in accordance with the preliminary design. The design resistance is caculated as follows:

$$R_{d,\vartheta} = \frac{R_{t,m} \cdot k_\vartheta \cdot k_n}{\xi_1 \cdot \gamma_{s,t}} = 314\ kN \geq E_{d,\vartheta} \qquad (11)$$

The combination of two Spinnankers (type XII / 8.0 / 15) represented on Figure 12 is therefore suitable for this steel hall.

Figure 12. Double Foundation

3.3 Case example 3: Foundation of a forest slide park in Montafon valley (Austria)

3.3.1 Design actions and subsoil conditions

The compression load $E_{k,G} = 22.4\ kN$ acting on the foundation in the direction ϑ = -63° corresponds to a design load of

$$E_{d,\vartheta} = 22.4 \cdot 1.35 = 30.2\ kN \qquad (12)$$

There is neither a soil profile or results of dynmic probing for describing the subsoil. The results of the load tests are therefore particularly important. The soil is most probably composed of a dense mixture of silt with sand and of gravel as part of an end moraine at around 1600 m over sea level. For the preliminary design, a friction angle of φ'_k = 33° and a soil weight of γ'_k = 17.0 to 17.5 kN/m³ are supposed.

3.3.2 Pull out test and safety design

A Spinnanker of type VI with a rod length of 3,0 m as single foundation has been chosen. The bearing capacity of this Spinnanker is estimated to 65 kN in the above soil conditions. The minimum test load P_p has been evaluated to 58 kN using Equation 8 with the following parameters: $\xi_1 = 1.4$ (one pull out test), $k_n = 1.0$ (single foundation), $k_\vartheta = 0.838$ (with a = 0.5 and ϑ = -63°) and $\gamma_{s,t} = 1.15$.

The test procedure and measurement systems are similar as for case example 1. The load has been increased up to 150 kN in 6 increments of 25 kN. The interpretation of the time-displacement and load-displacement curves leads to a bearing capacity $R_{t,m}$ of 71 kN, which corresponds to a head displacement of 3.5 mm.

The design resistance is then:

$$R_{d,\vartheta} = \frac{R_{t,m} \cdot k_\vartheta \cdot k_n}{\xi_1 \cdot \gamma_{s,t}} = 37\ kN \geq E_{d,\vartheta} \qquad (13)$$

The Spinnanker VI / 3.0 / 15 is therefore adapted as single foundation for the forest slide park represented on Figure 13.

Figure 13. Single footing / Forest slide park

4 CONCLUSIONS

This paper shows on one hand the extreme versatility of the system Spinnanker and on the other hand a relatively simple way to ensure a safe and economic design in accordance with european standards. The same procedure has been used here for analyzing the axial pull out and compression tests and determinate the ultimate limit state, independantly of the soil type and the direction of the design actions.

The design and installation procedure described in part 2.1 has gained increasingly in accuracy due to the extensive investigations already performed and the experience gained on the field. Considering the high number of available results, a precision of ± 10 % between preliminary design based on a detailed soil report and acceptance tests can be assumed.

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