Spinnanker – Experiences with a New Foundation and Anchor System

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Abstract. The Spinnanker is a new developed foundation and anchor system to lead forces into the subsoil. The Spinnanker can be installed almost on every type of terrain, even on steep slopes, in nearly all kinds of subsoil material. Based on comprehensive theoretical analysis and in-situ field tests the load deformation behaviour of the Spinnanker has been defined. Up to now more than 4,000 Spinnanker have been installed for permanent and temporary construction tasks. The Spinnanker consists of a steel plate and 6 or 12 steel bars with a length of up to 8 m. For the installation the steel bars are screwed into the subsoil. One person can install the Spinnanker in less than one hour without using any heavy equipment. The system does not need any concrete and can be removed totally without any parts remaining in the subsoil. The paper presents the theoretical approaches, the developed principle of the design and the application in engineering practice. For example the Spinnanker is used for anchoring and foundation of houses, farming and fabrication halls, slope stabilisation, auxiliary constructions (e.g. for overhead electricity line towers) and fixed-points for construction machines.

Keywords: Spinnanker, foundation, anchor, slope stability.

Conference topic: Design experiences and theoretical solutions.

Introduction

Based on their experiences in the field of protective structures the new start-up company Spinnanker GmbH from Austria developed an innovative, concrete-less soil anchor and foundation system named “Spinnanker”. Together with well-known scientific research institutions the theoretical background was investigated and a principle design concept was developed for several applications in engineering practice (Mayrhofer *et al.* 2010; Katzenbach, Leppla 2011). Basis for the investigation of the theoretical background and the developed principle design concept were comprehensive numerical simulations and in-situ field tests. The involved research institutions are:

- alpS – Center of natural hazards and risk management (Innsbruck, Austria);
- Technische Universität Darmstadt, Institute and Laboratory of Geotechnics (Germany);
- Technische Universität Graz, Institute of Soil Mechanics and Foundation Engineering (Austria);
- University of Innsbruck, Institute for Infrastructure, Division of Geotechnics and Tunnel Engineering (Austria);
- Federal Technical College Saalfelden (Austria);
- Vilnius Gediminas Technical University, Department and Research Laboratory of Geotechnical Engineering (Lithuania).

Description and installation of the Spinnanker

The Spinnanker consists of a circular cast iron steel plate, which is anchored into the ground with up to 12 threaded steel bars. The length of these threaded steel bars varies between 2 m and 8 m and depends on the loads and the soil conditions. The short code of the different types of the Spinnanker are based on the number of the threaded steel bars in Roman numerals, followed by the length of the individual bars in metres and the diameter of the bars in millimetres. Figure 1 shows a Spinnanker XII/2.0/15 with 12 threaded bars (length 2.0 m, diameter 15 mm) after a pull-out test (collapse load).

Fig. 1. Spinnanker XII/2.0/15 after pull-out test

Fig. 2. installation of a Spinnanker

The depth z_a of the subsoil investigation has to cover all layers which are significantly influenced by the construction. On slopes, the investigation depth has to be big enough to locate possible slide zones. The recommended investigations depth is $z_a \geq 4$ m below the end of the threaded bars. The installation of the Spinnanker is achieved by using handheld drilling machines (Fig. 1 right). This allows the installation in difficult terrain. The removal of the anchors can be done with the same equipment.

In-situ load tests and numerical simulations for investigation of the load deformation behaviour

For the investigation of the load deformation behaviour an extensive research and analysis programme was carried out. This research and investigation programme consists of small scale model tests, in-situ load tests in different soil conditions, different loading conditions and numerical simulations (Mayrhofer *et al.* 2010; Supp *et al.* 2010; Supp, Marte 2014). More than 60 in-situ load tests have been carried out using the Spinnanker type VI and XII with 6 respctively 12 threaded steel bars with a length between 2.0 m and 4.0 m and a diameter of 15 mm. Vertical compression loads, vertical tension loads and horizontal tension loads have been applied in the tests. The load tests have been carried out in non-cohesive and in cohesive soil material.

For vertical pull-out tests Figure 2 shows some examples of load displacement curves. On Figure 3 the results of in-situ load tests in non-cohesive soil material and on Figure 4 the results of in-situ load tests in cohesive soil material are displayed. Due to technical reasons some of the load tests in non-cohesive soil material could not be carried out until the collapse load.

For the Spinnanker type VI in non-cohesive soil the maximum vertical tension load was between 50 kN and more than 150 kN with displacements of about 3 cm, depending on the length of the threaded bars (Fig. 3). For the Spinnanker type XII in non-cohesive soil the maximum vertical tension load was between 90 kN and more than 190 kN with displacements of up to 1.5 cm, depending on the length of the threaded bars (Fig. 3). In non-cohesive soil the load displacement curves show a relatively small residual load capacity at large displacements.

Fig. 3. Result of vertical pull out tests in non cohesive soil

Fig. 4. Result of vertical pull out tests in cohesive soil

For the Spinnanker type VI in cohesive soil the maximum vertical tension load was up to 30 kN with displacements of up to 2.5 cm (Fig. 4). For the Spinnanker type XII in cohesive soil the maximum vertical tension load was between 30 kN and 70 kN with displacements of up to 2.5 cm, depending on the length of the threaded bars (Fig. 4). In cohesive soil material the load displacement curves show that the residual load capacity is slightly increasing at large displacements. Remarkable is that the Spinnanker type VI/4.0/15 has roughly the same load deformation behaviour as the Spinnanker type XII/2.0/15.

For horizontal load tests Figures 5 and 6 show some examples of load displacement curves. On Figure 5 the results of in-situ load tests in non-cohesive soil material and on Figure 6 the results of in-situ load tests in cohesive soil material are displayed.

For the Spinnanker type VI in non-cohesive soil the maximum horizontal tension load was up to 25 kN with displacements of up to 1.5 cm (Fig. 5). For the Spinnanker type XII in non-cohesive soil the maximum horizontal tension load was up to 55 kN with displacements of up to 1.5 cm (Fig. 5). In non-cohesive soil the load deformation behaviour of the Spinnanker is in principle the same for vertical tension loads as well as for horizontal tension loads.

For the Spinnanker type XII in cohesive soil the maximum horizontal tension load was between 55 kN and 65 kN with displacements of up to 2 cm (Fig. 6). In cohesive soil material the load displacement curves show that the residual load capacity is slightly decreasing at large displacements.

Fig. 5. Result of horizontal load tests in non-cohesive soil

Fig. 6. Result of horizontal load tests in cohesive soil

Fig. 7. Simulation of a loaded Spinnanker using Discrete-Element Method (DEM)

In order to determine the load capacity during the planning stage extensive numerical simulations using the Discrete-Element-Method (DEM) have been carried out. Figure 7 shows the numerical tests box with a modelled Spinnanker (Supp, Semprich 2010). To determine the soil mechanical parameters and the micromechanical

material properties of the particle-particle contact back-analysis of in-situ load tests have been carried out.

Design and safety concept

Based on the small scale tests, the in-situ load tests, numerical studies, first careful applications in engineering practice and the main geotechnical standard EC 7 (CEN 2008) a design and safety concept has been developed. For all applications it has to be proven, if the design values of the impacts E_d are smaller than the design values of the resistance R_d (Equations 1 and 2).

$$E_d = \gamma_G \cdot E_{G,k} + \gamma_Q \cdot E_{Q,k}; \quad (1)$$

$$R_d = \frac{R_k}{\gamma}. \quad (2)$$

Using the results of the in-situ load tests and the numerical studies design diagrams have been developed for the preliminary design of the Spinnanker considering the allowable displacements. For the long term use of Spinnankers the corrosion rate of the threaded bars has to be considered according to EAU 2012 (Hafenbautechnische Gesellschaft e.V., Deutsche Gesellschaft für Geotechnik e.V. 2012). According to other foundation and anchor systems 10% (3 Spinnanker minimum) of the installed Spinnankers of a project have to be tested in-situ regarding the load deformation behaviour. In the case of sensitive applications numerical analysis with parametric studies should be carried out additionally to estimate the effects of variation of the soil parameters.

The design and safety concept consists of the following stages:

- preliminary design based on the soil investigation and the developed design diagrams as well as on experiences of realized applications;
- definition of the safety factor depending on the application (permanent, non-permanent);
- quality control of the installation;
- in-situ load tests on the construction site.

In the following an example of the preliminary design is explained. A Spinnanker type XII in non-cohesive soil has to be designed for a static, characteristic, vertical load of $E_{G,k} = 45$ kN. Using the Equations 3 to 7 and the diagram displayed in Figure 8 the required length of the threaded steel bars can be determined to be 2.0 m. The defined safety factor for the resistances R is defined to $\gamma = 1.5$.

$$E_d \leq R_d; \quad (3)$$

$$\gamma_G \cdot E_{G,k} \leq \frac{R_k}{\gamma}; \quad (4)$$

$$\gamma \cdot \gamma_G \cdot E_{G,k} \leq R_k; \quad (5)$$

$$1,5 \cdot 1,35 \cdot 45 \text{ kN} \leq R_k; \quad (6)$$

$$91 \text{ kN} \leq R_k. \quad (7)$$

Fig. 8. Characteristic load capacities for a Spinnanker type XII/x/15, vertical displacement ≤ 2 cm

Applications of the Spinnanker in engineering practice

The experimental and numerical studies as well as already completed projects have proven the Spinnanker to be a universal foundation and anchoring system. The system can be used for permanent and non-permanent applications for horizontal and vertical loads (tensile or compressive). Some challenging applications that have been realized are:

- anchoring of auxiliary construction, e.g. for construction and forest machines (Fig. 9);
- fixed-points for the installation of overhead electricity line towers (Fig. 10);
- anchoring of the snow avalanche protection “Snowgripper” (Fig. 11);
- slope stabilization (Fig. 12);
- removeable foundations of structures, containers etc. (Fig. 13);
- foundation of skywalk (Fig. 14).

Fig. 9. Anchoring for timber harvesting

Fig. 10. Anchoring for installation of an electricity line tower

Fig. 11. Snow avalanche protection system “Snowgripper”

Fig. 12. Slope stabilization

Fig. 13. Removable foundation for container compound

Fig. 15. Steel hall founded on Spinnanker in sensitive environmental area

Fig. 14. Sky walk founded on Spinnanker

Fig. 16. In-situ load test in Abu Dhabe (UAE)

A special application of the Spinnanker as an anchor system is the temporary back-anchoring for the installation of overhead electricity towers (Fig. 10). The towers have a height of up to 74 m (380 kV). The characteristic tension load on one anchor point is up to 140 kN with an inclination of 45° to the vertical axis.

For the biggest fish plant in Germany a protection hall was planned. Original planning was a steel construction founded on single foundations with reinforced concrete blocks. The building and environmental authorities gave the permission for the steel construction, but they defined for the allowable foundation system, that there should be the possibility of the total reconstruction. No construction elements should remain in the the sensitive environmental area. Concrete elements were not allowed. The characteristic vertical load on a middle pillar single foundation point was up to 320 kN.

At the construction site the soil and groundwater conditions can be described as follows:

- 0–6 m: silt and clay;
- 6–30 m: sandy gravel;
- groundwater level: 0.8 m below surface.

The foundation was realized by 76 Spinnanker built as a hybrid foundation, consisting of the Spinnanker and a cylindrical screw-anchor (Alpinanker) in the centre. The length of the bars and the screw-anchor was 8 m. Figure 15 shows the steel hall under construction. Each steel hall has a length of 120 m and a width of 16.6 m.

Conclusions

The extensive scientific research by small scale tests, in-situ load tests and numerical studies as well as the experiences made by realized projects demonstrate the the positive characteristics of the Spinnanker and are the basis for the design and safety concept.

The Spinnanker is an innovative, concrete-less anchor and foundation system. Remarkable is the very small carbon foot print. The Spinnanker can be installed without any heavy machines or equipment and can be used for permanent and non-permanent applications. Up to now more than 4,000 Spinnanker have been installed successfully. The main parts of the design and safety concept are the wide spreaded experiences and the in-situ load tests for every project on the construction site. For example Figure 16 shows an in-situ load test for a mobile phone tower in Abu Dhabi, United Arabian Emirates (UAE).

The mobile phone tower has a height of 60 m and a characteristic vertical compression load of 250 kN per anchor point. The Spinnanker had 12 bars ($\varnothing$ 15 mm) with a length of 6 m. The load test was carried out with vertical compression loads and vertical tension loads. The test results showed that the ultimate bearing capacity of vertical compression loads is about 130% of the ultimate bearing capacity of vertical tension loads. The measured ultimate bearing capacity for tension loads was 370 kN at a vertical displacement of 1.2 cm. The

final design of the foundation of the mobile phone tower was four anchor points with 12 bars each with a length of 6 m.

Regarding the possible aggressiveness of the soil and groundwater the design of the anchor and foundation system Spinnanker is always on the safe side using more anchor points and longer bars. To optimize the Spinnanker in aggressive soil and groundwater conditions the thickness of the bars will be increased to 18 mm.

The research about further possible applications showed, that the Spinnanker can be combined with concrete elements. These hybrid foundation systems offer the possibility to transfer higher loads into very difficult and aggressive soil. The basic studies on the load-displacement behaviour for the determination of the length of the steel bars were carried out with short bars with a length between 2–4 m. By additional load tests and the gained experiences of realised projects the data base is continuously increasing. Today steel bars with a length of up to 8 m are installed for very high loads and very small allowable displacements.

Regarding the loads on the system and the correlation to the length of the bars, the scientific basic.

In 2016 there will be a European technical certification which documents the positive characteristics of the Spinnanker officially. The positive characteristics of the Spinnanker can be summarised as follows:

- foundation and anchor system for permanent and non-permanent applications;
- application for stabilisation of slopes;
- easy and quick to install without any heavy machines or equipment;
- installation even in very difficult terrain (e.g. steep slopes);
- for vertical, horizontal or inclined tension and compression loads in all kinds of soil material (exclusively rock);
- load can be applied directly after installation;
- ductile system behaviour;
- system can be totally deconstructed without any remaining parts in the soil;
- very cost-efficiently and cheaper than other systems for the same application;
- possibility to combine the Spinnanker with concrete elements or additional steel elements (e.g. Alpinanker = screw-anchor) to transfer higher loads into difficult and aggressive soil;
- possibility to combine 2 and more Spinnanker on a very tight place to a single foundation/anchor

- point to transfer very high loads into the soil respectively to minimise the displacements;
- modularity of the system (mix and match);
- very small carbon foot print;
- easy to transport, post and handle;
- re-usable in many cases.

Meanwhile the Spinnanker is used in several countries in Europe. Several other countries show a big interest on the Spinnanker, e.g. from Middle East, Asia and North Africa. At the moment the scientific research and the test phases for new fields of applications are in progress.

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