**- GUIDANCE NOTE -**

**THE DESIGN OF STEEL HELCIAL PILES**

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# 1 Introduction

This guidance note has been prepared by the Federation of Piling Specialists (FPS) in response to concerns raised by members that the Annex A within BS 8004:2015 does not do enough to explain how steel helical piles work, and thus how to approach the design. This document is designed to be read in conjunction with the aforementioned Annex, and the recently revised ICE Speciﬁcation for Piling and Embedded Retaining Walls (Third Edition), which now includes a section covering the installation of steel helical piles. It is not intended to act as a replacement for either of the documents mentioned, although the author hopes that it can be drawn upon for future revisions of BS 8004.

It is also not the author’s intention to recommend the helical piling system over any other for specific loading conditions, as such a decision would be subject to a variety of considerations based on individual project specifics. Likewise, any derivation of actions under BS EN 1990, for design to BS EN 1997-1, would include the correct and relevant partial factors applied to any actions imposed on the foundation, taking into account the magnitude and frequency over the design life. With reference to utilising the helical piling system for cyclical loading conditions, considerations given in cl.4.2.3.3 of BS 8004:2015 for cyclical loading would still be relevant, and over-arching.

Whilst A.2.4, Note 1, references the reader to Howard A. Perko’s publication “Helical Piles: a practical guide to design and installation” (2009) for details on the design of helical piles, it is an American publication, and will offer the reader very little input in terms of adapting the design for use with BS EN 1997-1:2004+A1:2013 (Eurocode 7, henceforth referred to as EC7). Where possible, the author makes recommendations to any adaptations to the design of helical piles in order facilitate a design to Eurocode. This guidance note should be used for reference only, and the FPS and author assume no liability for its use.

# 2 Design Considerations

## 2.1 Compressive resistance of helical piles

With steel helical piles there are two accepted methods of design: the individual bearing plate method, and the cylindrical shear method.

The individual bearing plate method applies when the spacing between plates is large, so that each helix will act independently of the other(s) (as shown in Figure 1a). If the spacing between the plates is small, then the helical plates will act as a group, and the bearing capacity of the pile will incorporate the bearing of the bottom plate and the side shear along the cylinder of soil that is formed between each plate (as shown in Figure 1b). This soil cylinder is misleadingly referred to as a “plugged shaft” in Appendix A of BS 8004:2015; as many helical piles use an open steel tube, a “plugged shaft” could allude to plugging at the end of the tube, and this comment suggests to incorporate the end bearing resistance of the tube itself which is small in relation to the bearing resistance of the helix plates.



If the pile only has one bearing plate, then the individual bearing method can only be adopted for design. If piles have more than one plate, it is prudent to use both methods and limit the result to the lowest calculated value. Whilst the exact point at which the transition between individual bearing failure and cylindrical shear is not known, and will vary depending on the soil type, it is prudent to use a helix spacing-to-diameter ratio of 3 as a rule-of-thumb when applying the note in A.5.1, checking sufficient vertical spacing between the helices as it prevents the overlap of the stress bulbs beneath each plate.

## 2.2 Shaft friction

As per A.5.1.3, shaft friction is generally ignored in the design of helical piles, but the reasons for this is not outlined. Generally speaking, most manufactured helical piles are smooth steel-shafted tubes, and have coupling sleeves which are slightly larger in diameter than the shaft, and these create a void/space around the shaft during installation. Similarly the bolts which hold these section into place will also carve a path of increased diameter throughout the soil during installation. Square-shafted piles, such as the A B CHANCE® system, can create a round hole of loosened soil immediately adjacent to the shaft during installation. Wobbling during installation may also cause the soil to separate from the pile shaft along the uppermost sections of the pile, especially if piles are installed without a guide mast. As it is difficult to quantify many of these reasons shaft adhesion is often just ignored in the pile design, but in reality it is present, regardless of installation method, and it is not unreasonable to assume large diameter piles may develop a large proportion of their capacity in shaft friction.

Figure 1. Illustrative sketch of the two accepted helical pile design methods: Individual Bearing Plate (a), and Cylindrical Shear (b). Source: Perko, H. (2009). Helical Piles: A Practical Guide to Design and Installation. John Wiley & Sons, Inc. Chp. 4, Fig. 4.1, p.104.

A.5.1.3, and following note are misleading and the shaft friction along the pile could be taken into account (and probably should) if testing gives better than expected results, even when considering designs carried out via the cylindrical shear method. Designers should factor in a reduction of the shear strength of the soil to account for the reduced friction of soil on bare or galvanised steel, and may also need to reduce this further for other surface treatments. However, if you are piling in certain soils, i.e. London Clay, then it would be more prudent to use lower values for an *α*-value to reflect appropriate soil behaviour during installation.

It is also recommended taking shaft friction over an effective length (Heff) rather than the whole pile length to account for any void formation by the plate during installation.

Under Eurocode design (BS EN 1997-1:2004+A1:2013) the two method helical piling design approaches can be applied when using the relevant Design Approaches. For the resistance factors, due to the fact that the system is not auguring the ground and the plates are seen to displace the soil, a designer can adopt the R4 values for a driven pile as per A.NA.6. For shaft friction in the design, the author recommends potentially adopting the reciprocal M2 material set values as per A.NA.4 for calculation of *γ*s in the GEO limit state, and lower bound M1 values for the STR limit state.

## 2.3 Pull-out resistance of helical piles

Whilst design of pull-out resistance is briefly mentioned in the Appendix A (A.2.4, Note 2, and A.5.2) it only represents a very basic understanding and should be expanded upon. In theory, the bearing and pull-out capacity of a deeply embedded helical pile should be similar, but as the soil can be disturbed above the helical plates during the pile installation a designer can apply a reduction factor to the tensile capacity. A disturbance factor of 0.87 is recommended by Perko, but it can vary according to soil type and installation equipment.

A.5.2 is also misleading as it is essentially a repetition A.5.1.3, and shaft friction along Heff could be taken into account (and probably should) if testing gives better than expected results. Heff being the effective length of shaft above the top helix.

Under Eurocode, the author would recommend adopting the reciprocal M2 material set values as per A.NA.4 for pull-out design where testing is not adopted, which can be revised either to include the shaft friction for calculation of *γ*s;t in the GEO limit state, or to include the M1 set should favourable testing results be obtained.

It is also recommended that helixes must achieve a critical depth to ensure a deep mode of behaviour, which is not an active recommendation of Annex A of BS 8004:2015. If a helical anchor is too shallow then the weight of the soil above it will be insufficient for the pile to provide suitable resistance to tension. Shallow failure can occur when the bearing plates are located too close to the ground surface, or for helical pile used as anchors where the plates are located too close to the active soil wedge. A failure would see a shearing of the soil around the helical bearing plates, and a lifting up of the cone of soil above the upper-most helix.

## 2.4 Torque

We are in agreement with comment A.2.1.9 which states that the design of helical piles should be based on a conventional soil mechanics approach supported by testing when combined by an empirical approach, and with A.2.1.10 that helical piles should not be designed solely on empirical rules relating to the applied torque measured during pile installation. What requires further clarification are points A.7.12 – A.7.14, as they refer to installation torque, and design installation torque, as critical values within the installation procedure and yet no mention is given to how these values are determined or their impact on design. As a result, the designer is therefore left in a paradoxical situation where the torque is both of great importance, and of little consequence in the design and installation of a helical pile.

Whilst most literature on helical piling will tell you that whilst it is very difficult to predict, torque can be used as a way of verifying the axial capacity of a pile in both compression and tension. It is widely accepted that the relationship stated by Hoyt and Clemence (1989) is used to calculate pile capacity from the final installation torque, where a variable capacity-to-torque ratio is used, and is dependent upon a variety of factors: soil conditions, shaft size and shape, and application of the pile (be it tension or compression).

The number of helical plates also has an impact on the torque as plates can work against each other depending on installation and soil conditions, often resulting in very high torque.

Rather than enforce capacity-to-torque ratio values into the code for the derivation of torque, helical piling contractors should be able to demonstrate to clients and engineers their methods of calculating the anticipated minimum and design torques in their design calculations, backed up with empirical data through testing.

Maximum torque values used in design and installation should be determined by the robustness of the structural elements used in the formation of the helical pile. As helical piles are a bespoke product, all contractors should be able to detail the torsional resistance of the steel tube pile shaft to avoid twisting during installation. In a modular helical piling system particular attention must also be made to the bolt connection between sections, as this too can act as the weakest point of the system and determine to maximum torque values for installation. It is advisable for helical piling contractors to limit the torsional resistance of the structural elements of a pile to the serviceable limits, so as to ensure no weakening of the structure occurs during the installation.

Attention should also be given to the difference between the maximum and design torque of a helical pile during installation, allowing for a safety buffer for the installation crew to have the opportunity to “punch in” should slightly harder bands or a movable obstruction is encountered during installation without over-stressing the piles.

## 2.5 Auguring of piles

As per A.7.2, a crowd force is applied to the pile head to ensure that the penetration rate outlined in A.7.1 is achieved. Despite this application of crowd, if the penetration rate falls outside of these limits, the pile can be said to be auguring (or spinning), and the pile capacity should be reassessed (as stated in A.7.3).

The result of this lack of penetration is that a void is formed under the helix, and only the lead edge of the helix will bear onto the ground. If this occurs at depth, this may invalidate the design. The bearing pressure area in compression is equal to a line load on the lead edge of the helix, and the end of the pile shaft, rather than the complete area of the helix plate. This will also prove an issue in tension as the auguring of the material may also impact on the strength of the soils above the ground, particularly in sensitive soils. The end result is that the pile must either be discounted, or the capacity reduced unless testing can be undertaken to check the performance of the pile.

## 2.6 Horizontal loading

No guidance is given in BS 8004:2015 Annex A as to the design of the lateral resistance of helical piles. However, the lateral resistance of the pile is due to the performance of the steel tube that forms the pile shaft, and the strength of the surrounding soils. Therefore, any number of industry-accepted methods can be adopted in line with 6.4.5 of BS 8004:2015 to calculate lateral resistance and displacement, including elasticity theory, p-y curves, subgrade reaction models, or any other approved numerical models.

Due to the modular nature of the system, there are many different products and solutions offered by a number of helical piling contractors that can help improve the lateral performance of the system. These range from adding an oversized, or cruciform collar to the top of the pile to add lateral resistance by increasing surface area, welding steel plates to the top of the pile to increase the surface area, or by simply increasing the thickness or diameter of the upper sections of tube to improve the moment capacity of the pile. Not all of these solutions may be appropriate for use depending on the various site and project constraints, but the designer must appreciate any implications of each one adopted in the design, for example when using an oversized connection the effect of the creation of a void/space around the shaft during installation.

## 2.7 Pile spacing and grouping

A.2.3.2 infers that helical piles are not to be spaced closer than 4x helix diameters apart (centre-to-centre on plan), and this is in line with guidance from Report AC358, ICC-Evaluation Services, Inc. (2007), and is a standard across the helical piling industry.

In terms of group effects, the ultimate capacity of a pile group is determined using a similar method to the cylindrical shear method, and must be considered in the design.

## 2.8 Pile settlement

As part of an EC7 pile design it is now down to the pile designer to predict the settlement of the pile at working load. Reference should be made to 6.4.4 for approved methods of calculating settlement, although these are no substitute for a static pile load test. One could argue that due to the lack of exposure a number of clients and engineers have with helical piles, testing would help improve confidence in their adoption as a mainstream foundation solution.

Two points should be considered: firstly if the shaft friction was ignored in the design then it should also be discounted in the settlement prediction. If, as previously discussed, the pile behaves better than expected, then you can consider reintroducing it into both the pile design and the settlement calculation. Secondly, thought should also be given to the settlement prediction of a helical pile with multiple plates, especially in ground of variable strata. Elastic shortening of the steel under working load should also be considered.

## 2.9 Structural design

Elaborating on the points outlined in section A.6 the pile shaft section requires a check for buckling resistance, and a moment and axial force check.

The pile is unlikely to fail in buckling, although a buckling check should be carried out as a standard when a pile is installed through very soft strata. A helical pile is most likely to fail under bending, and thus the check for MEd ≤ MN,Rd is critical. An estimated pile fixity point is used in these design checks, and this can be determined either by software/modelling, or by the calculation methods outlined in 6.4.5 of BS 8004:2015. Where a modular system is used this point of fixity must not fall below, or clash with the connection between the two top sections of the pile.

All steel piles are at risk from attack from electrochemical corrosion, rather than sulphate chemical attack as per concrete piles. Corrosion rates of soil is dependent on a variety of different factors, such as low pH values, chloride salt content, moisture content, oxygen availability and the presence of certain bacteria. Stray currents and the electrical connection of the structure to another metal are also factors that can affect the corrosion rate of the metal. The general method to deal with corrosion of a helical pile is a combination of utilising a coating of galvanising, and by including a sacrificial thickness of steel in the pile wall. Sacrificial anodes can also installed on some piles where soil corrosivity is classified as severe. Cathodic protection can also be utilised to deal with stray currents and electrical connection, usually in the form of a wire, or strip of metal running away from the pile and into the ground.

Individual helical piling contractors should be able to advise further as to their methods for countering corrosion, and provide some level of empirical data to satisfy any potential concern with the design life of their piles.

It is prudent that any structural check for a helical pile be carried out with the reduced thickness of steel, so as to ensure consistent performance throughout its design life. Failure to do so may result in the requirement of remediation work further down the line.

Finally, although this is more of a fabrication issue rather than a design issue, it is important to note that the welds on helical piles between the plate and the steel tube are a particular vulnerability. Welding is covered briefly in section B7.6 of the third edition of the ICE SPERW, where the relevant ISO standards covering quality control are listed. It is imperative that all welds are checked thoroughly for quality before installation to endure the system is fit for purpose.

# 3 Construction

## 3.1 Installation

The installation process of a steel helical pile is covered in great depth in both BS 8004:2015 Annex A, and sections B7 and C7 of the recently revised ICE Speciﬁcation for Piling and Embedded Retaining Walls (Third Edition). The author sees no urgent need to address or alter these sections at this stage. Helical piling contractors should, however, be able to provide site specific method statements and risk assessments outlining their processes when dealing with the issues raised in the above documents, in particular to their reporting of installation torque, monitoring penetration, and their re-design and justification processes for those piles which are deemed to be auguring, or do not achieve minimum or design torque.

## 3.2 Testing

Static load testing of steel helical piles is covered in depth in sections B7.8 and C7.8 of the recently revised ICE Speciﬁcation for Piling and Embedded Retaining Walls (Third Edition).

# 4 References

BS 8004:2015, BSI (2015)

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