

The threaded displacement piling system

Sistemul de realizare a piloților de îndesare cu spire

Lóránd Sata[1], Sanda Manea[2]

[1]Technical University of Civil Engineering
bd. Lacul Tei nr. 122 - 124, cod 020396, Sector 2, București, Romania
E-mail: sata_lorand@yahoo.com

[2]Technical University of Civil Engineering
bd. Lacul Tei nr. 122 - 124, cod 020396, Sector 2, București, Romania
E-mail: sanda_manea@utcb.ro

DOI: 10.37789/rjce.2025.16.1.1

Abstract.. *Screwsol is one of the recent deep foundation solutions for the "screw" type threaded displacement piling methods. The system is successfully applied in the range 330/500 to 530/700mm not only in Great Britain, France, but also in Central – East Europe, fully covered in by the standard EN 12699:2015 [1]. The paper present by means of more than 250 simple and instrumented loading tests the technological details, the constructional principles and the choosing of dimensions, the application possibilities, the design approaches as well as sustainability evaluation.*

Key words: *displacement piles; screw piles; design approach; sustainability*

Rezumat. *Screwsol este una dintre soluțiile recente de fundare de adâncime prin piloți de îndesare cu spire de tip „șurub". Sistemul este aplicat cu succes în gama de dimensiuni 330/500 până la 530/700 mm nu doar în Marea Britanie, Franța, ci și în Europa Centrală și de Est, fiind pe deplin reglementat de standardul EN 12699:2015 [1]. Lucrarea prezintă, prin intermediul a peste 250 de teste de încărcare simple și instrumentate, detalii tehnologice, principii constructive și modul de alegere a dimensiunilor, domeniile de aplicare, abordările de proiectare, precum și evaluarea sustenabilității.*

Cuvinte cheie: piloți de îndesare, piloți de tip șurub, abordare de proiectare, sustenabilitate

1. Introduction

One of the recent optimal soil displacement drilling solutions is given by the rotary displacement piling system, the Screwsol concept, defined as follows:

Pile in which the pile or pile tube comprises a limited number of helices at its toe, and which is installed under the combined action of a torque and a vertical thrust. By the screwing-in and/or by the screwing-out, the ground is essentially laterally displaced,

The article was received on 19.04.2024, accepted on 24.02.2025 and published on 14.03.2025

and no soil is removed. The technology is covered by the standard ASRO SR EN 12699:2015[1].

The article presents a list of simple and instrumented loading tests for several load types; technological details, design approaches; constructional principles and the choosing of dimensions; application possibilities; the ecological impact analysis and evaluation of the Screwsol rotary displacement piling system [2] [3].

The pile identified by two diameters (core / threads) is applied in the range 330/500 to 530/700mm (Figure 1) [4].

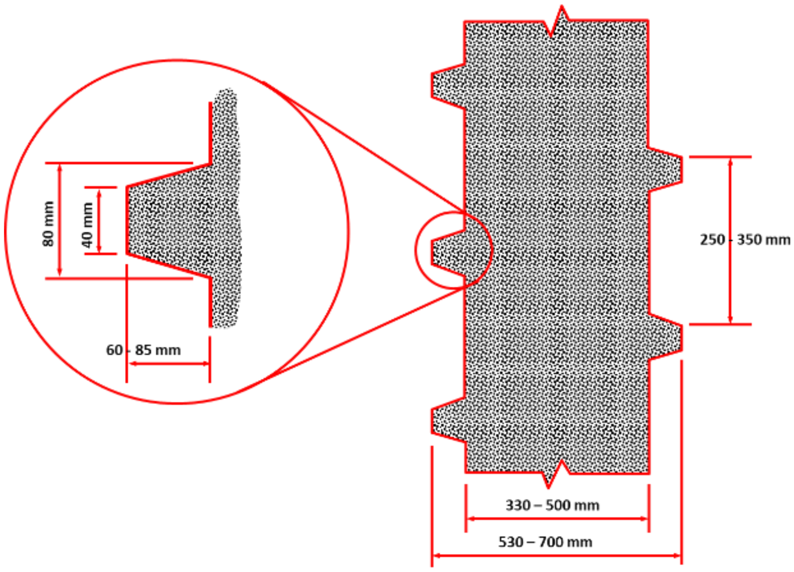

Figure 1. Screwsol pile longitudinal section and thread details.

2. Alizeu wind farm load test / 2013

The tested pile was a Screwsol pile with a diameter of d=330/500 mm (meaning 330 mm cylinder diameter and 500 mm external diameter) and a toe depth of H = 20.95 m from ground level (actual pile length of L = 20.60 m), reinforced on its entire length, to provide support for the strain gages and to protect the pile head from local crushing at high loads. Four reaction piles were used for the load test, executed with the same technology.

The static load test was carried out in equal steps of 125 kN, until failure. Application of a load increment was conditioned by stabilization of settlements for the previous step. Additionally, the pile was equipped with 17 extensometers and during the load test the deformation of the concrete was monitored with a frequency of 1 reading / minute.

Strain gauge measurements were processed in several steps to determine the detailed pile behaviour, and to confirm or contradict the preliminary conclusions based on the classical load test results.

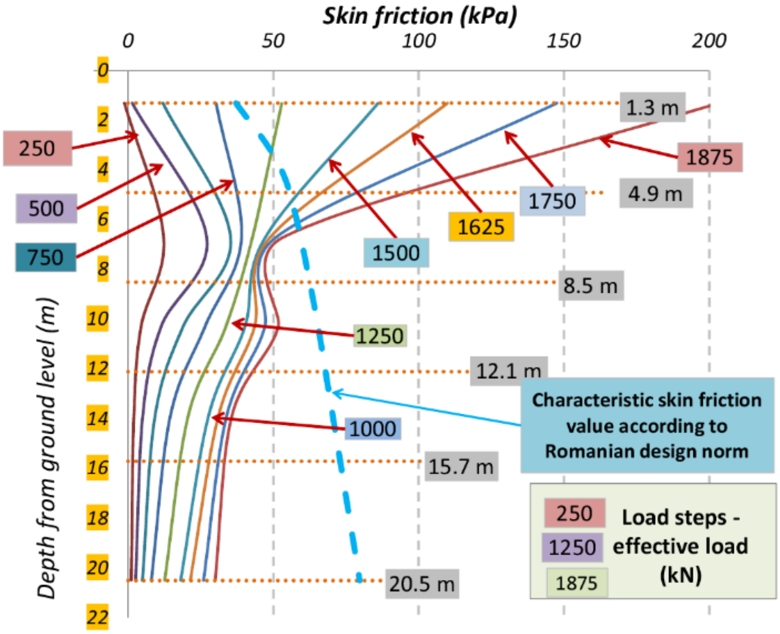

Figure 2. Skin friction diagram.

Pile failure occurred at the 16th load step (2000 kN), most likely by crushing of the pile head due to eccentrical application of the load. This observation is supported by the load-settlement diagrams of the four individual sensors that measured the settlement of the pile, located at the four corners of the pile.

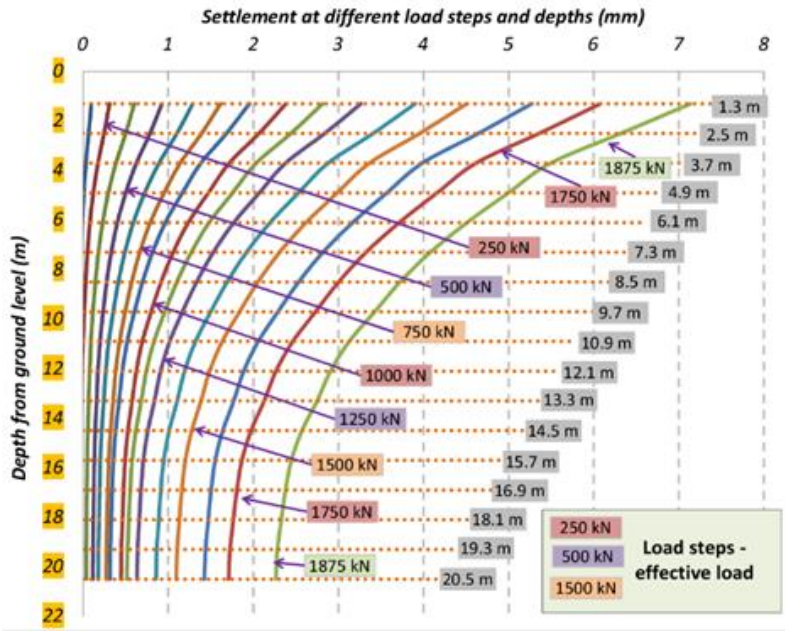

Figure 3. Settlement diagrams.

In case of the Screwsol pile, the most important uncertainty is the choice of the cross-sectional area A (which automatically influences the lateral surface considered in the calculation of skin friction –Figure 2). Also, the displacement of the soil needs to be taken into consideration when computing pile forces and skin frictions. A third uncertainty is the elastic modulus of the combined concrete-steel pile, which can be safely evaluated for design purposes.

The results presented (Figure 3) consistently reveal the pile's tendency to consume most of the loads in the upper half of its length. In case of efficiently designed non-displacement piles it is expected that most of the loads are transferred through the lower part of the shaft (skin friction) and by tip resistance. Skin frictions in the upper few meters reach values of 200 kPa and more, compared to a maximum of 80 kPa given by the design norm.

However, in this case there are factors that suggest a different behaviour. Due to the presence of the threads, combined with the displacement of the soil, larger shear stresses may develop in the upper part of the shaft. Equally importantly, the soil is homogenous, even at the pile toe level, while in most design scenarios the soil layers towards the pile toe are significantly stiffer.

3. Logistic center Craiova load tests / 2021

The CPT-based design of the foundations was performed according to EC7 [5]:

$$R_{c,k} = \left(R_{b;k} + R_{s;k}\right) = \frac{R_{b;cal}+R_{s;cal}}{\xi} = \frac{R_{c;cal}}{\xi} = Min\{\frac{(R_{c;cal})_{med}}{\xi_3};\frac{(R_{c;cal})_{min}}{\xi_4}\} \quad (1)$$

Based on the calculations few of the determined pile lengths were the following:
D330/500 – 950kN – L=16.05m
D330/500 – 1100kN – L=17.25m
D430/600 – 1450kN – L=16.55m

Five preliminary, instrumented load tests were executed on area A2. The instrumentation consists of strain gauges and base plates. The strain gauges were placed on the reinforcement cage at a vertical spacing of 1.5 m, with 3 gauges per each level being installed to achieve more precise results (Figure 4) and to confer redundancy in case some gauges would be damaged during pile installation. The base plates were installed on the bottom of the reinforcement cages, practically at pile toe level.

It is noted that all 5 test piles exhibited a load-displacement pattern which is characteristic for friction piles, represented by a considerable quasi-elastic domain until 875 kN to 1625 kN, which represents 17.5 % up to 32.5% of the representative diameter, considered as 50 mm, given that most of the load (and practically all service load) is carried by the shaft. These values are also very close or even exceed the structural capacity of the pile, which can be approximated as A_{int} x $f_{c,d}$ = 0.085 m2 x 16.7 MPa = 1425 kN.

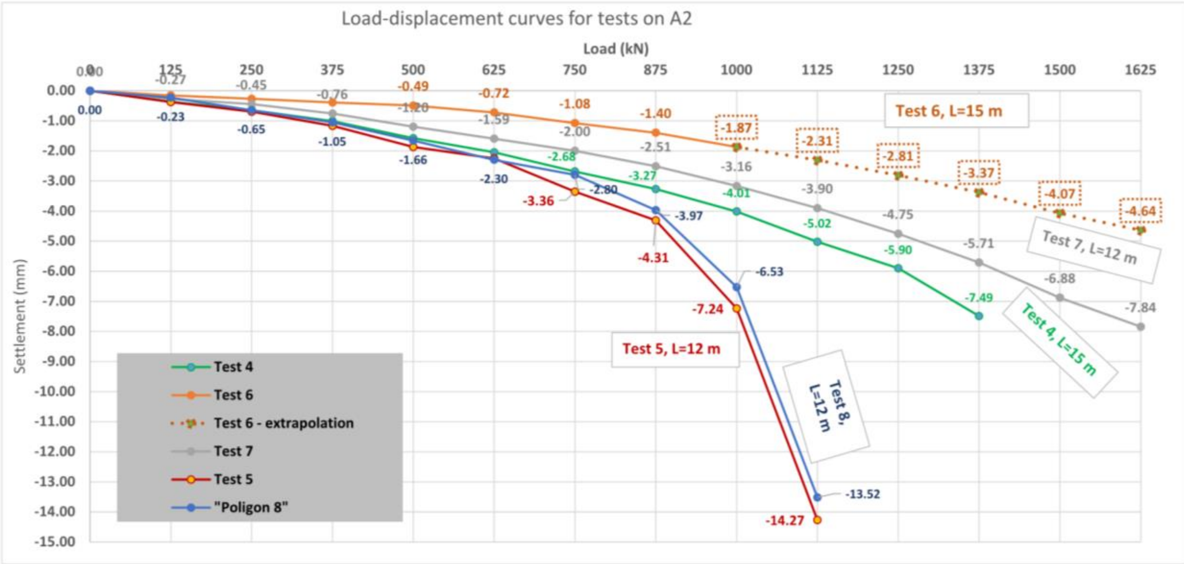

Figure 4. Load-settlement curves for all tests (5 piles).

However, it is noted that all other tests exhibited an extremely favourable pile behaviour. In case of two tests (test 4 and 7) the cracking of the pile head occurred after 1375 to 1625 kN, which are sufficiently large values of ultimate capacity to allow for an efficient pile design after division with partial safety factors. In case of test 6, for which pile head cracking occurred after 1000 kN, an extrapolation was performed, given the large pile length and the extremely small pile displacements (<2 mm) up to this point, to avoid unnecessary overdesign.

The distribution of the skin friction and toe resistance is presented in Figure 5, using a first approach in which the skin friction was calculated while the toe resistance was determined by subtracting the total skin friction from the load step applied during testing.

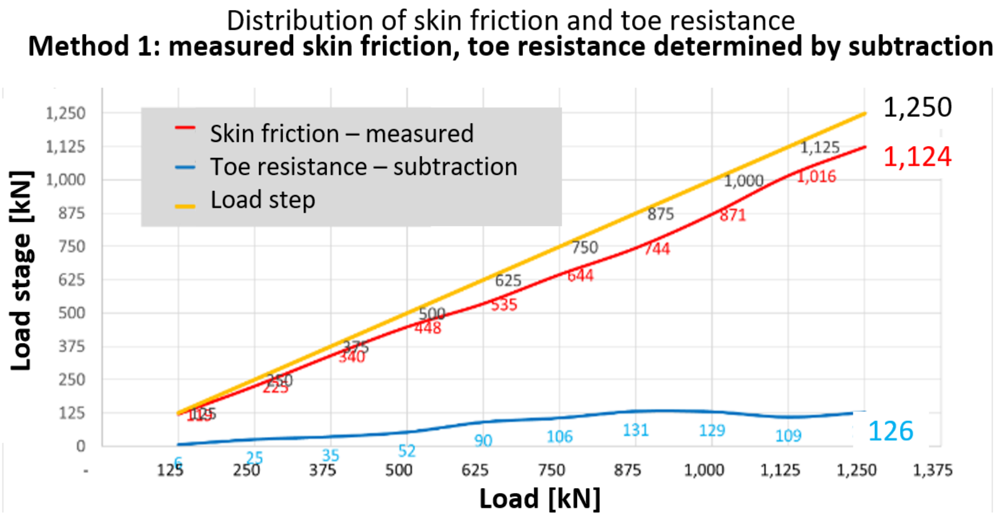

Figure 5. Distribution of skin friction and toe resistance – method 1, test 4.

The diagram shows that the pile shaft carries the largest part of the loads, approximately 90% and practically constant during the load steps.

4. Design approach of Screwsol piles

The Screwsol threaded piling system is recognized for integrating and enhancing the advantages of various piling systems, making it a highly efficient and versatile solution in foundation engineering. The specific benefits of the Screwsol system were highlighting its versatile diameters, relatively low torque requirements, and the use of

Smooth shaft displacement piles and threaded shaft displacement piles are two types of deep foundation elements used to support structures, particularly in challenging soil conditions. The load-bearing capacity of both types primarily relies on end-bearing at the pile tip and skin friction along the pile shaft (Figure 1).

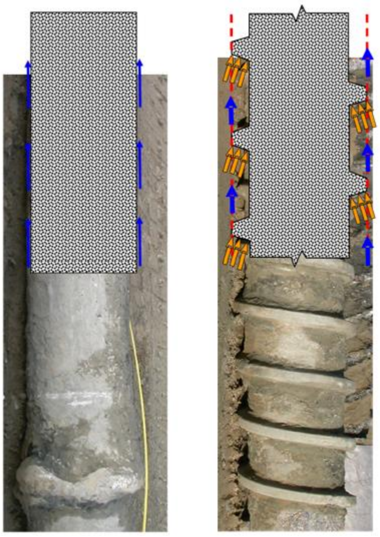

Figure 6. Smooth shaft and threaded shaft soil displacement piles schematic load transfer mechanism

The threaded shaped shaft increases the surface area in contact with the soil, enhancing skin friction resistance. The threaded design provides superior axial resistance, making these piles ideal for tensile load applications, such as wind turbine foundations and transmission towers.

Design based on the prescriptive Method as Outlined in Romanian Norm NP123:2010 [6] and its Updated Version NP123:2022 [7]

This method is based on the guidelines provided in the Romanian Norm NP123:2010 [6], which serves as a prescriptive framework for designing screw piles. Initially, this norm was utilized for the analysis of the first load tests conducted on such piles. The NP123:2010 [6] has since been revised and updated with the release of NP123:2022 [7], which incorporates more recent research findings and technological advancements. This updated version provides enhanced guidelines, reflecting the latest best practices and improved methodologies for evaluating the load-bearing capacity and performance of soil displacement threaded screw piles.

Using the empirical method for cast-in-place floating bored piles and the assumptions mentioned above, the bearing capacity is determined bellow:

$$R_{c,d} = A_b \times q_b \quad /\gamma_{b2} + U \times \sum (q_s, k_i, l_i)/\gamma_{s2} - G_{pilot} \ (kN) \tag{1}$$

where:

$R_{c,d}$: bearing capacity, design value (kN);

A_b: cross-sectional area at pile toe (m^2);

$q_{b,k}$: toe resistance, characteristic value (kPa);

U: shaft perimeter (m);

$q_{s,ki}$: unitary skin friction (kPa);

l_i: depth of elementary soil layer (<2 m);

$\gamma_{b,2}$, $\gamma_{s,2}$: safety factors for toe and shaft resistance (dimensionless).

The interpretation of the monitoring results of the presented pile tests confirms that the pile geotechnical ultimate capacity exceeds the maximum load value given in the norm. It was also observed that high specific skin friction values were recorded which is significantly different than it is indicated in the design norm NP123-2022 [7]. These results suggest a very good behaviour of threaded piles in loose, medium dense non-cohesive soils as well as in soft, medium consolidated clays and confirm the efficiency of these pile types compared to equivalent bored piles.

The author proposes the already known formulae where the lateral friction is be expressed by the following relationship:

$$q_{s,k,i} \sim \tau_f = (\sigma_i \times tan(\phi_i') + c_i') \times k_{SCR} \tag{2}$$

The author introduced the “k_{SCR}“ correlation factor, to establish a relationship between the values set in the design norm and the values of the studied load test results. The author suggests using this correlation factor to enhance the accuracy, reliability, applicability of the calculation, by making it better reflect the real-behavior of the variables in question.

The k_{SCR} correlation factor is considered to be a critical parameter in the design of soil displacement threaded screw piles, influencing the calculation of the pile's load-bearing capacity by accounting for the soil's mechanical properties and its interaction with the pile shaft. The proposed values for the k_{SCR} correlation factor can be summarized as follows:

- Non-Cohesive Soils (Sands and Gravels): k_{SCR} = 0.55 - 0.65

The proposed values for non-cohesive soils reflect the load transfer mechanism predominantly relying on the frictional resistance along the pile shaft and the shear of the interlocked soils with the surrounding compacted soils. The proposed k_{SCR} values within this range ensures that the load-bearing capacity calculations remain conservative, accounting for potential variations in soil density and compaction levels.

This conservative approach helps prevent overestimation of pile performance and enhances the safety and reliability of the foundation system.

- Cohesive Soils (Clays and Silts): k_{SCR} = 0.90 - 1.00

These higher values reflect the load transfer mechanism as the shear resistance of the soil against lateral movement.

By aligning the k_{SCR} values with the inherent properties of different soil types, engineers can ensure that the load-bearing capacity calculations are both accurate and safe, leading to optimized pile designs tailored to specific site conditions.

The partial safety factors $\gamma_{b,2}$, $\gamma_{s,i,2}$, mentioned above are safety factors for toe and shaft resistance and they are dimensionless. They represent technology (pile execution method and concreting technology) and soil related (around the pile shaft and at pile toe) factors, therefore their discussion in relation of the Screwsol cast in situ threaded soil displacement method is rather relevant.

The safety factor for the shaft resistance ($\gamma_{b,2}$), is described as conditioned by the execution technology of the piles versus the soil around the pile shaft. For the Screwsol method the values 1,90 respectively 1,20 is proposed by the author, in cohesive and respectively non-cohesive soils around the piles shaft, for the reasons as follows:

- in cohesive soils, the improvement / the compaction of the soil around the piles shaft is rather limited, while the execution technology (installation steps) is very similar to those of the CFA (continuous flight auger)
- in non-cohesive soils, where the Screwsol method advantages are clearly demonstrated and where the improvement / the compaction of the soil around the pile by the means of the interlocking phenomena provides the best output, the safety factor is proposed with the values given by the norm for the “Driven casing and driven compacted concreting” and the “Vibrated casing and vibrated compacted concrete” technologies

The safety factor for the toe resistance ($\gamma_{s,i,,2}$), is described as conditioned by the concreting technology of the piles versus the soil at the pile toe. For the Screwsol method the values 1,20 respectively 1,20 is proposed by the author, in cohesive and respectively non-cohesive soils at the pile toe, for the reasons as follows:

- in both cohesive and non-cohesive soils, the concreting technology is very similar to those of the CFA (continuous flight auger), the concreting of the pile starting with the slight withdrawal of the drilling tool and simultaneous pumping of the fresh concrete, through the hollow core of the auger, thus injecting and filling of all the cavities and the contact between the pile toe and the surrounding soil is ensured

Design according to the In-Situ Test Results (CPT) Based Method, as Described in Eurocode 2, Annex D [5]

This approach relies on in-situ test results, particularly using Cone Penetration Testing (CPT), as outlined in Eurocode 7-2, Annex D [5]. This method involves conducting field tests to directly measure soil properties such as cone resistance and sleeve friction. These measurements are then used to determine the bearing capacity and behavior of screw piles under different loading conditions. The CPT-based approach allows for a more site-specific and accurate assessment of pile performance, tailoring the design to the actual soil conditions encountered at the project location.

Eurocode 7-2, Annex D [5], describes the calculation formula for the maximum compressive strength of a pile:

$$F_{max} = F_{max;base} + F_{max;shaft} \tag{3}$$

where:

$$F_{max;base} = A_{base} \times p_{max;base} \tag{4}$$

is the maximum base resistance

and

$$F_{max;shaft} = C_p \int_0^{\Delta L} p_{max;shaft;z} dz \tag{5}$$

is the maximum shaft resistance

where: A_{base} is the cross sectional area of the base, in m2;
C_p is the circumference of the part of the pile shaft in the layer in which the base of the pile is placed, in m;

Maximum base resistance

$$p_{max;base} = 0.5 \times \alpha_p \times \beta \times s \times (\frac{q_{c;I;mean} + q_{c;II;mean}}{2} + q_{c;III;mean} \tag{7}$$

where $p_{max;base}$ is the specific resistance at the base of the pile, while $q_{c;I;mean}$, $q_{c;II;mean}$, $q_{c;III;mean}$, $q_{c;z;a}$ are the CPT cone resistances measured with different methods.

$p_{max;base} \leq 15MPa$

α_p - pile class factor

β - expanded pile toe shape factor (between 0.6 – 1.0)

s - non-circular pile toe shape factor (1.0 for square shape)

At the critical depth the calculated value of qb becomes a minimum.

q_{cm} - mean of the q_c values over the depth from 3D below the base up to the level 1.5D above the pile base

q_{cIm} - mean of the q_{cI} values over the depth from the pile base level to critical depth level.

q_{cIIm} … mean of the lowest q_{cII} values over the depth going upwards from the critical depth to the pile base level, in which progressing upwards a value is only considered if it is lower than the previous one.

q_{cIIIm} … mean of the lowest q_{cIII} values over a depth interval from the pile base level to a level of 8 times the pile base diameter above the pile base. This procedure starts with the lowest q_{cII} value used for the computation of q_{cIIm}.

Maximum shaft friction

$$\mathbf{p_{max;shaft;z}} = \boldsymbol{\alpha_s} \times \mathbf{q_{c;z;a}} \tag{8}$$

where: $p_{max;shaft;z}$ is the specific resistance on the lateral surface of the pile,

α_s - shaft friction coefficient

$q_{c;z;a}$ - value of q_c at depth z

Based on the results of the preliminary, later on of the simple, complex and instrumented load tests performed on Screwsol piles and their results correlations with the CPT values, the following values are proposed by the author for the coefficients ∝p and ∝s (Table 1):

Table 1.

α_p and α_s values proposed for Screwsol piles in various soils

Soil type	Soil type	$\propto_p$	$\propto_s$
Non—cohesive	gravel, sandy gravel	0,90	0,005
	gravely sand, coarse sand	0,90	0,007
	medium and fine sand	0,90	0,009
Cohesive	Silt, low plasticity clay	0,80	0,025
	Medium and high plasticity clay	0,80	0,033

The suggested values are consistent with the ranges specified by Eurocode 7 [5] for both driven piles and continuous flight auger (CFA) piles. This alignment supports the claim that Screwsol piles effectively combine the superior bearing capacity characteristics typical of driven piles with the versatile installation techniques associated with bored piles.

The proposed values are derived from extensive correlations established by the author of this thesis through comprehensive analysis and testing conducted over nearly two decades, from 2005 to 2024. This research involved more than 100 different sites, where over 400 load tests and more than 1000 Cone Penetration Test (CPT) measurements were performed.

5. Analysis and evaluation of the CO2 footprint of Screwsol

The use of materials (concrete, steel) is responsible for approximately 95% of total CO2 emissions generated by construction activity.

For the example, it was considered a project with 500 piles with a length of 10.0 m, in two versions: executed with CFA technology and diameter of 600mm, respectively Screwsol technology and diameter 430/600, their bearing capacities being considered to be similar.

The analysis demonstrates that CFA technology with a 600mm diameter results in a significantly larger (30% higher) carbon footprint (Figure 7) compared to Screwsol technology with a 430/600mm diameter. This difference highlights the importance of selecting appropriate piling methods to minimize the carbon footprint and contribute to broader climate change mitigation and environmental conservation efforts. By opting for Screwsol technology, construction projects can achieve more sustainable outcomes, reducing their overall carbon footprint and contributing to environmental conservation efforts. Moreover, the proper selection of piling method is not just a technical decision but a strategic one that has far-reaching implications for the environment. By prioritizing sustainable and less carbon intensive piling techniques, the geotechnical construction industry can play a pivotal role in reducing greenhouse gas emissions, conserving natural resources, and fostering a more sustainable built environment.

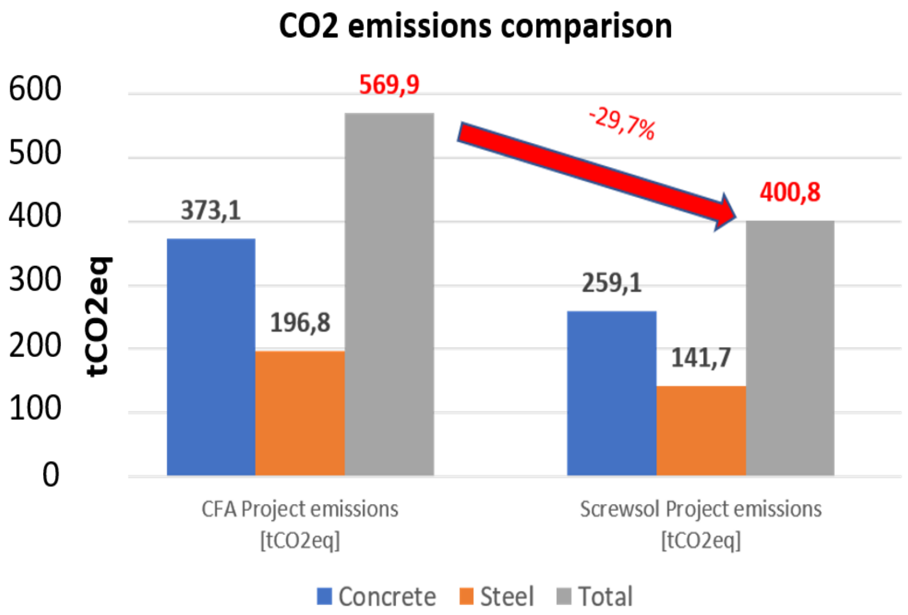

Figure 7. CO2 emissions for CFA and Screwsol.

6. Conclusions

The applicability of Screwsol has been successfully proven both in non-cohesive soils, but also in medium stiff and plastic clay conditions. The execution length of the piles is limited by the characteristics of the in situ soil and the refusal criteria of the soil – drilling torque combination.

The maximum efficiency of the piles is obtained for non-cohesive soil conditions terrain – fine and medium – in loose or medium density. In the case of cohesive soils, the efficiency is high plastic clays. Due to the fact that the dynamic effects produced during execution are reduced through the execution technology, they can also be used to treat soils with liquefaction potential. The presence and level of the groundwater has neither negative influence on the execution technology nor to the efficiency of the piles.

References

[1] ASRO. SR EN 12699:2015, Execution of special geotechnical works - Displacement piles (in Romanian: Execuția lucrărilor geotehnice speciale. Piloți de îndesare).

[2] T. Kaltenbacher, L. Sata, Á. Deli. ”The applications of the Screwsol soil displacement piling solution, Közúti és Mélyépítési Szemle, Budapest, Hungary” (in Hungarian: (A Screwsol talajkiszorításos cölöpözés alkalmazásának lehetőségei), 2008.

[3] L. Sata, ”Small and large diameter soil displacement Screwsol piles in the deep foundation practice”, Proceedings of the 10th Geotechnical Conference (V4), Ráckeve, Hungary, 2005

[4] L. Sata, S. Manea, ”Screwsol – threaded displacement pile”, Revista Construcţiilor, ISSN 1841-1290, Bucharest, Romania. (in Romanian: (Screwsol – Pilot de îndesare înşurubat), 2012.

[5] ASRO. SR EN 1997-2:2007, Eurocode 7: Geotechnical design - Part 2: Ground investigation and testing (in Romanian: Eurocod 7: Proiectarea geotehnică. Partea 2: Investigarea şi încercarea terenului).

[6] NP 123-2010: Regulations on the geotechnical design of pile foundations (in Romanian: Normativ privind proiectarea geotehnică a fundațiilor pe piloți).

[7] NP 123-2022: Regulations on the geotechnical design of pile foundations (in Romanian: Normativ privind proiectarea geotehnică a fundațiilor pe piloți).