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For the resistance mechanism associated with the subsidence of both the concrete piece and the tubes in the ground, and after analyzing some theoretical frameworks, the methodology proposed by Brinch Hansen (1961) was selected. This methodology is based on the Terzaghi equation (Terzaghi, 1943), and some corrective parameters are applied that allow us to approximate the existing mechanisms in the studied foundation, as well as the consideration of drained or undrained situations (see below).

$$q_u = qN_q\, s_q d_q i_q + c\, N_c\, s_c d_c i_c + 0.5\, \gamma\, B\, N_\gamma\, s_\gamma d_\gamma i_\gamma$$

$$N_q = tan^2(45 + \frac{\phi}{2})e^{\pi \cdot tan\phi}$$

$$N_c = \left(N_q - 1\right)cot\emptyset$$

$$N_\gamma = 2\left(N_q + 1\right)tan\emptyset$$

$s_q\, d_q\, i_q\, s_c\, d_c\, i_c\, s_\gamma\, d_\gamma\, i_\gamma$ corrective parameters

where:
$q_{u:}$ unit ultimate resistance.
c: cohesion.
γ: density.
q: Pressure on the base of the foundation (depends on the depth)
B: Width at base of the foundation
N_c,N_q,N_γ: capacity load factors (dimensionless)

The ultimate resistance of the foundation will be

$$Ru = \text{Rh} + 4 * \sum_{i=1}^{n} (\text{Rpi})$$

where:

Ru: Ultimate subsidence resistance of the foundation
Rh: Ultimate subsidence resistance of the concrete piece as an isolated piece.
n: Number of segments that the tubes are divided into. This allows for the consideration of the variation of the pressure (q) with the depth, as well as considering the existence of diverse kinds of ground or the water level if it exists.
Rpi: Ultimate subsidence resistance of the studied segment of the tube

The theoretical framework previously described allows for the evaluation of the maximum capacity of the new foundation for diverse types of soils, introducing the variables:
Φ : Internal soil friction angle
C: Cohesion
γ: Density.
H: Foundation embedment (depth of the inferior face of the concrete piece).

In the next table (table 1) the proposed method is applied, considering a foundation with 20 cm embedment , a soil density of 15 kN/m^3 and homogeneous ground with varying values of internal friction angle and soil cohesion.

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4. Numerical simulations

The interaction between the new foundation and the soil has been analysed using the numerical tool, PLAXIS 3D, a common software used for the analysis of the interaction of foundations with the soil. This analysis allows for the consideration of three dimensional resistance mechanisms as well as the introduction of the geotechnical features of the soil and strength-deformation characteristics of the concrete piece and the steel bars that form the foundations. The points highlighted in the model are:

- The geometry is generated based on a 5m×5m×2.5m prism, the piece and the four tubes that form the foundation inside the prism. The elements that form the discretization mesh have and average length of 0.03 meters (see Figure 6).
- The concrete piece of the foundation is modelled following an elastic linear model with non-rigid interactions on ground-piece interfaces.
- The tubes are modelled with elastic 'embedded pile' elements, commonly used to simulate piles.
- In order to simulate the soil geotechnical features a Mohr-Coulomb elasto-plastic model is used.

The model was calibrated with the data obtained in some load tests. The next figure 7 shows the adjustment of the model to the data of a load test, where four cycles of vertical increasing loads were applied on the foundation.

The numerical model provided several conclusions. Among them:

- It is reasonable to consider that the ultimate strength of the foundation against the vertical loads transmitted by the structure is the sum of the resistance to the subsidence of the concrete piece and the resistance to the vertical penetration in the ground of each of the four tubes of the foundation. In a comparative analysis, considering the presence and the absence of the tubes gave the new foundation an important added resistance and more stiffness (see Figures 8 and 9).
- The numerical modelling, once the relevant calibrations had been done, was good enough to predict the load/settlement relation observed in real essays.
- The numerical model can simulate the behaviour of diverse types of soil through the variation of its geotechnical parameters. Therefore, the model can estimate the maximum load capacity of the foundation, allowing for a comparison with the maximum load capacity obtained from the analytical analysis. This analysis shows that the capacity obtained with the analytical analysis was inferior to the capacity obtained from the numerical model (see Table 2).

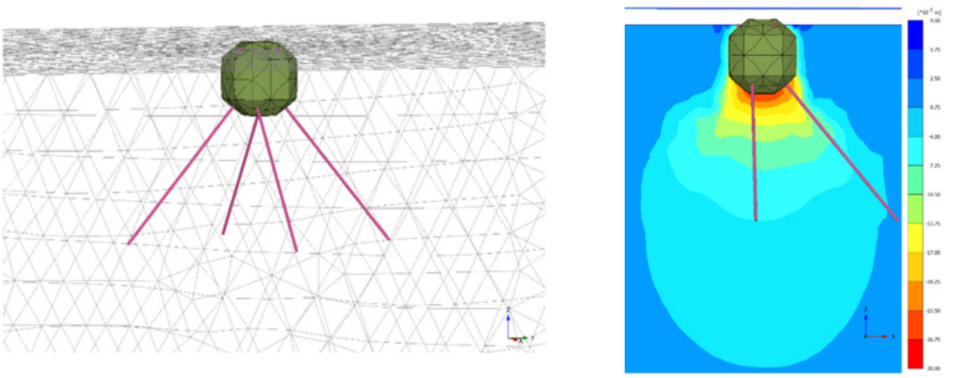

Figure 6.
Discretization mesh (left) and analysis where movements are represented (right)

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Behaviour and performance analysis against gravitational loads of a non-traditional, precast, removable and reusable shallow foundation

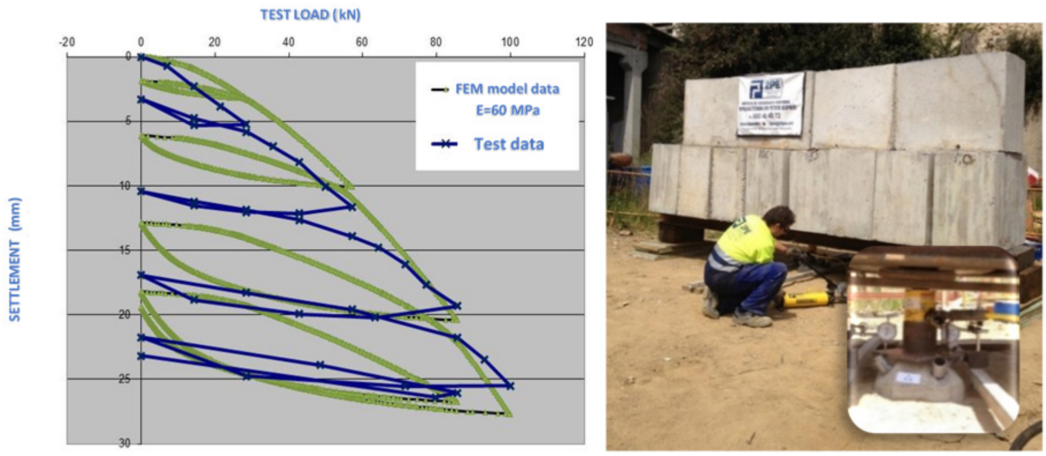

Figure 7.

Results of the load test where loads were applied in phases (left). Photograph of the test assembly (right)

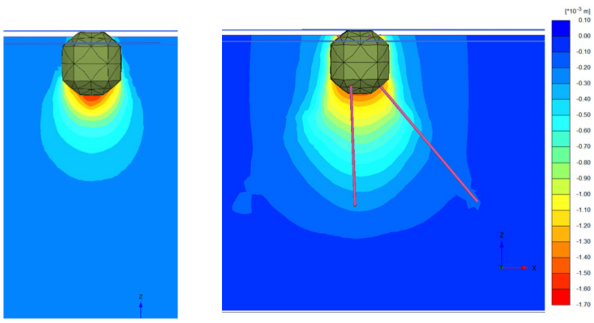

Figure 8.

Movement field considering only the concrete piece (left). Movement field with the full foundation (right)

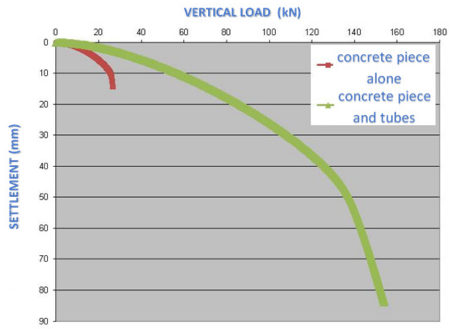

Figure 9.

Comparison of the load/deformation relation considering the concrete piece without tubes(red) and the complete foundation (green)

Internal friction angle (º)	Cohesion (kPa)	Ultimate resistance (Analytical method) (kN)	Ultimate resistance (numerical model) (kN)	Observations
20	5	22	>39	From 39 kN the model presents stability problems. It is assumed that this value is close to the breaking point.
25	5	35	>100	From 100 kN the model presents stability problems. It is assumed that this value is close to the breaking point.
30	5	63	>100 (150)	At 100 kN the model stops without stability problems. Studying the load deformation curve, the breaking point is estimated at 150 kN.
35	5	110	>100 (180)	At 100 kN the framework stops without stability problems. Studying the load deformation curve, the breaking point is estimated at 180 kN.
0	15	15	>90	From 90 kN the framework presents stability problems. It is assumed that this value is close to the breaking point.
0	50	48	>100 (180)	Since 100 kN the framework stops without stability problems. Studying the load deformation curve, the breaking point is estimated at 180 kN.

Table 2.

Estimated ultimate resistance in the numerical model (column 4) compared to the estimated ultimate resistance using the proposed analytical method (column 3)

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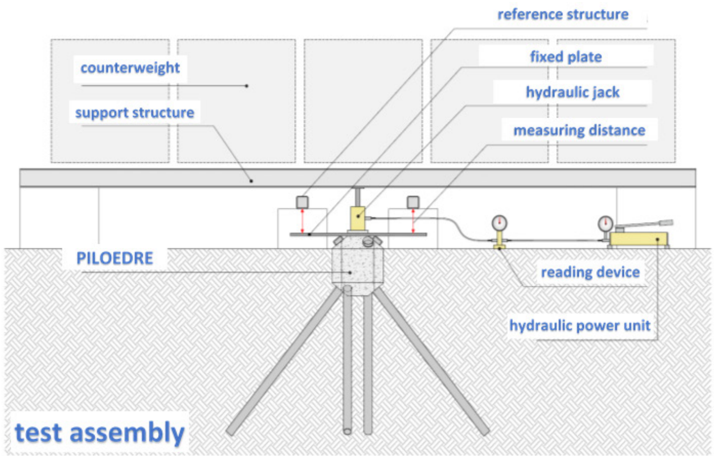

Figure 10.
Load test assembly sketch (left). Load test photograph (right)

Internal friction angle (°)	Cohesion (kPa)	Ultimate resistance (analytical method) (kN)	Ultimate resistance (load test) (kN)	Observations
20-24	0-5	Between 11 and 25	>26	4 load test were done with a minimum value of 26 kN and maximum value of 62 kN (average 43 kN)
25-30	0-20	Between 18 and 80	>80	11 load test were done with a minimum value of 80 kN and a maximum value of 120 kN (average 90 kN). Two of the load tests could have reached higher values but the capacity of reaction of the system didn't allow it.
30-35	0-20	30-120	>120	2 load test were done, both exceeding the maximum capacity of reaction of the test system,120kN.

Table 3.
Estimated ultimate resistance on the load test (column 4) compared to the estimated ultimate resistance using the proposed analytical methodology (column 3)

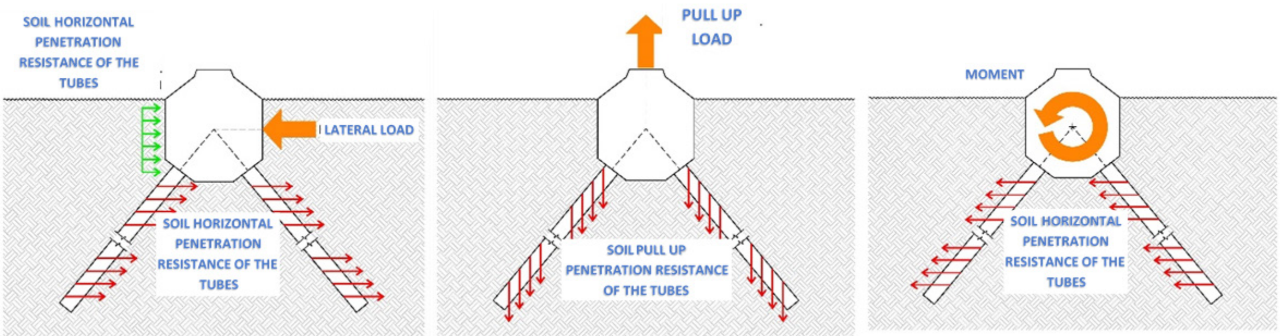

Figure 11.
Components of the loads: lateral, pull up and torsion

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5. Experimental testing

In order to better understand the performance and behaviour of the new foundation, a series of load tests was done (Figure 10). For the realisation of these tests, nine test fields were identified and characterised with geotechnical surveys and field tests.
The load tests required a previous study for their design, with the objective of providing the researched data and agreeing with the generally accepted regulations. The regulation used for the elaboration of the protocols was the Standard Test Method for Pilar Under Static Axial Compressive Load from ASTM [1]. This regulation is usually applied to static load tests on deep foundations.

The data obtained from the load tests was used to adjust the numerical model explained in the previous chapter, and allowed us to verify that the proposed analytical method used to estimate the ultimate capacity of the new foundation resulted in estimations inferior to the ones obtained in load tests (see Table 3).

6. Conclusions

This article shows a few of the results from part of the investigation on the function of a non-traditional foundation typology formed by a concrete piece with four steel bars inserted diagonally at a 40° angle with the vertical axis. All in all it weighs about 50 kg. This foundation is characterised by being prefabricated, mountable with manual tools, removable and reusable.
Specifically, this article presents an analytical verification tool for calculating the ultimate resistance of the new foundation against vertical descendent forces. This analytical method is based on the assumption that the resistance mechanism of the new foundation can be reinterpreted as the combination of two traditional resistance mechanisms: the associated mechanism of the resistance of the concrete piece to subsidence and the mechanism associated with the vertical sink resistance of the four tubes.
The validity of the developed analytical method has been proven using numerical modelling to simulate in 3D the interaction of the foundation with different kinds of soils. These numerical models have allowed us to get close to the actual behaviour of the new foundation and to verify that the designed analytical method estimates lower resistance values, so it is on the safe side, if you compare it to the ultimate resistance obtained by a complex numerical 3D model.
With the exposed analytical and numerical study, an intense series of load tests on the new foundation has been done. The data obtained has allowed us to develop numerical models and to verify that the result of the analytical method for determining the ultimate capacity of the new foundation is also on the safe side.
This article is focused on analysing the behaviour of the foundation against vertical descendent loads. This is the first step towards understanding the behaviour of the foundation against generic loads with ascendant, lateral and torsion components (Figure 11).

Acknowledgements

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Notes

(1) ASTM., " Standard test Methods for Deep Foundations Under static axial Compressive Load", Designation D1143/D1143M-07, American Society for Testing and Materials.

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References

Brinch H. J., "A General Formula for Bearing Capacity", Bulletin n° 11, Geoteknisk Institut, Danish Geotechnical Institute, Copenhagen 1961.

Tarrago D., Gens A., and Rosas J., "A New Re-usable Shallow Foundation for light loads. Load Tests and Analysis", Proceedings of the 19th International Conference on Soil Mechanics and Geotechnical Engineering, Technical Committee 307,Seoul 2017, pp. 3409-3412.

Terzaghi K., " Theorical Soil Mechanics",John wiley & Sons Inc., New York, London, 1943, pp. 118-143.