MODIFIED SOIL TESTS FOR SCOUR ANALYSIS ON OFFSHORE WINDFARM FOUNDATIONS

JORGE SORIANO-VICEDO[1], JORGE LUENGO FRADES[1],
JAVIER GARCÍA-BARBA[1] & VICENTE NEGRO-VALDECANTOS[2]
[1]University of Alicante, Spain
[2]Technical University of Madrid, Spain

ABSTRACT

The analysis of the scour processes following the pile driving procedures in offshore wind platforms is one of the major problems associated with this new form of clean energy generation. At present there are no scaled studies carried out analyzing the mechanical and deformational behavior of both the material of which the pile supporting the engine and the wind shovels is made (large steel hollow piles with a diameter of 8 m and a thickness of 15–20 cm) as well as the soil where the pile is driven. Usually these elements are installed on a very low granulometry sand displaced from the limits of dry beach–wet beach towards the offshore limits and where, due to this, it cannot return back to its natural state in its previous location. In addition, the few scaled studies carried out on dry soil similar to the existing one in the area of installation of the turbines has not considered a fundamental aspect such as the presence of seawater. This paper presents results obtained from tests to analyze the behavior of the base material on which the turbines are installed (degraded sands). These tests are the direct shear testing and a modification of the California bearing ratio (CBR) test to be carried out on completely submerged samples. The objective is to compare the results with those obtained in standard tests and analyze their suitability for field studies in offshore windfarms.

Keywords: offshore, wind platform, CBR, modified, soil, foundation.

1 INTRODUCTION

The objective of this study is to analyze the behavior of the degraded sands on which offshore wind farms are installed [1], [2], trying to avoid scouring and liquefaction processes [3]–[6]. In the works that have been carried out, the real state of the submerged soil where the foundation is built has not been considered. A material with similar characteristics to the real one has been assessed but under dry conditions, as has happened with the PISA project [1], where the trials of the foundation study for marine turbines were carried out onshore.

For this research, the following tests similar to "in situ" trials [7] were carried out: granulometric analysis, direct shear test and a compaction test such as the California bearing ratio (CBR) test.

2 MATERIALS AND METHODS

2.1 Granulometric analysis

The study has been carried out according to the UNE-EN 933-1 standard [8] "Ensayos para determinar las propiedades geométricas de los áridos (Tests to determine the geometric properties of aggregates)". The test was realized on two types of quarry granular samples, one from Algueña and another from Abanilla. The objective was to determine the basic granulometric characteristics to characterize the sands, such as the granulometric curves and the grain diameter (Table 1, Fig. 1).

WIT Transactions on Engineering Sciences, Vol 125, © 2019 WIT Press
www.witpress.com, ISSN 1743-3533 (on-line)
doi:10.2495/CMEM190181

Table 1: Grain size data.

Algueña				Abanilla		
Mesh width (mm)	% Partial retention	% Cumulative retention	% Pass	% Partial retention	% Cumulative retention	% Pass
4	0.00	0.00	100.00	0.00	0.00	100.00
2	0.22	0.22	99.78	0.45	0.45	99.55
1	32.99	33.20	66.80	36.95	37.40	62.60
0.5	26.79	59.99	40.01	22.54	59.95	40.05
0.315	12.70	72.70	27.30	11.47	71.42	28.58
0.25	6.63	79.33	20.67	5.21	76.63	23.37
0.2	4.35	83.68	16.32	4.15	80.77	19.23
0.16	4.87	88.54	11.46	4.83	85.61	14.39
0.125	4.09	92.64	7.36	3.80	89.40	10.60
0.09	4.09	96.73	3.27	5.19	94.60	5.40
0.063	3.19	99.91	0.09	4.76	99.35	0.65
Base	0.09	100.00	0.00	0.65	100.00	0.00
TOTAL	100.00	100.00		100.00	100.00	
D50 (mm)	0.686			0.721		

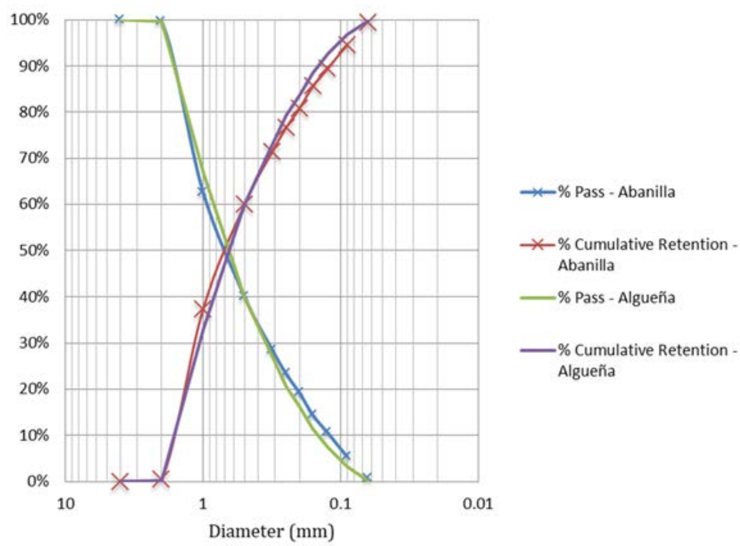

Figure 1: Distribution of grain size.

2.2 Direct shear test

The direct shear test was carried out according to the UNE 103 401 standard [9] "Determinación de los parámetros resistentes al esfuerzo cortante de una muestra de suelo en la caja de corte directo (Determination of the shear resistant parameters of a soil sample in the direct cutting box)" for each sand sample. The test is the consolidate-drained (CD) one, recommended for granular soils.

For the preparation of the sample, it has been chosen to pour the sand into the box, making sure that it falls from a height that prevents its compaction (Fig. 2). This option has been chosen to test the material in the conditions that would be found on the seabed, on which the material is deposited by its own weight. According to the standard, as in sandy soils, the consolidation occurs almost instantaneously; a speed of 1 mm/min was chosen so that the break lasts between 5 and 10 minutes.

Figs 3–6 show the graphs of the relationship of displacements, the break and the relationship of tensions, which determines the friction angle and the cohesion of each material (Figs 7 and 8).

2.3 CBR test

Two types of CBR tests were carried out, one as stated in the UNE 103 502 standard [10] "Método de ensayo para determinar en laboratorio el índice CBR de un suelo (Test to determine the CBR index of a soil in the laboratory)" and another with an important difference that is explained below. Both tests share the following aspects in the preparation of the samples:

Figure 2: Pouring the sand into the box.

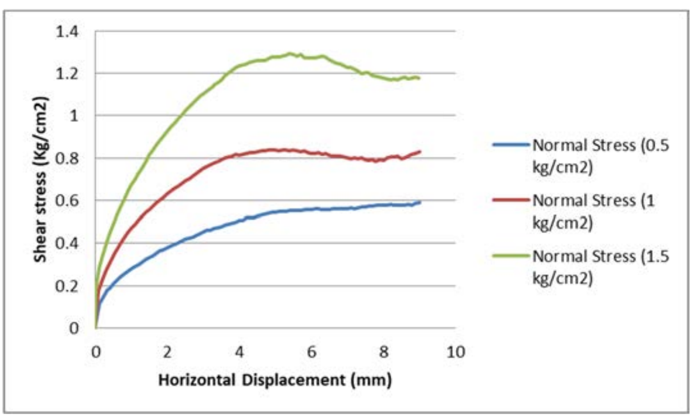

Figure 3: Breaking point on Abanilla sand.

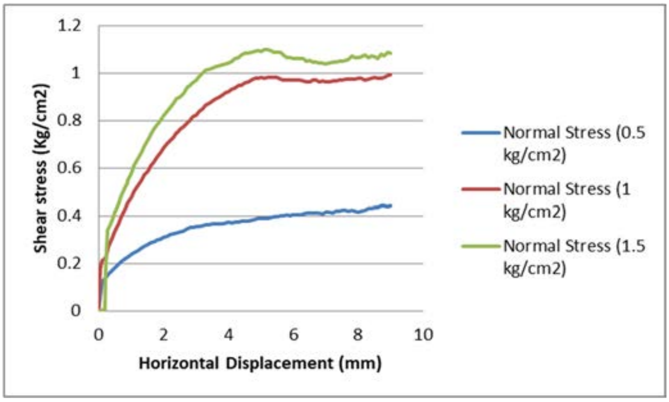

Figure 4: Breaking point on Algueña sand.

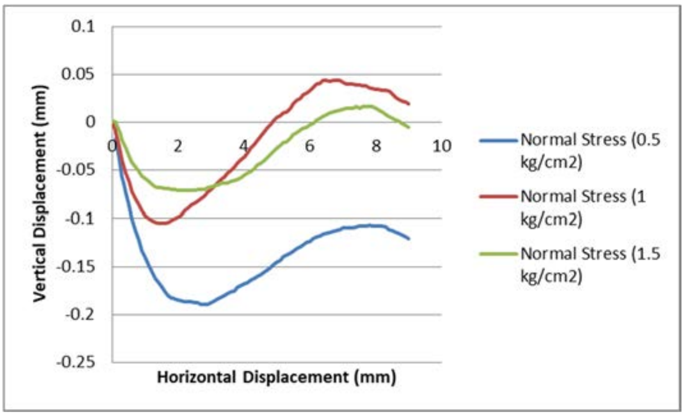

Figure 5: Displacements on Abanilla sand.

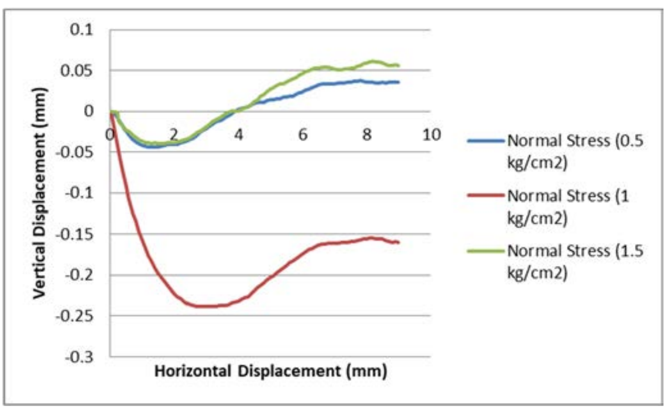

Figure 6: Displacements on Algueña sand.

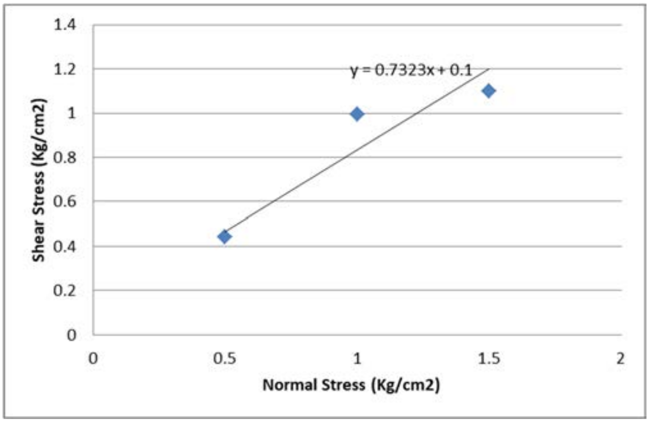

Figure 7: Stresses on Algueña sand (friction angle: 36.2°; cohesion ≈ 0 kg/cm^2).

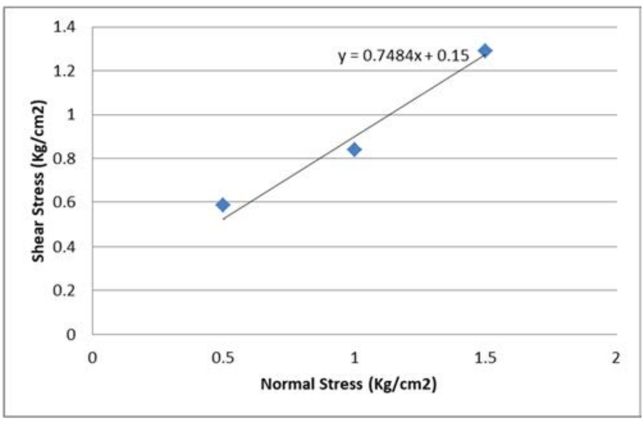

Figure 8: Stresses on Abanilla sand (friction angle: 36.8°; cohesion ≈ 0 kg/cm^2).

- Compaction in three layers mediating 15 blows per layer with the 2.5 kg mace that falls freely from a height of 305 mm. The sample has only been compacted by 15 blows because it was intended to apply a corresponding compaction energy with 25% of the compaction energy of the normal proctor. This is done to simulate the conditions of the material on the seabed, where it is not compacted, but has been deposited over time.
- The samples are immersed in containers filled with water for 72 hours (3 days). This time period is enough to saturate the granular soil.

The objective of these two tests was to compare the behavior of soil in dry penetration and submerged situations.

2.3.1 CBR standard test

For this test, three samples were tested for each type of granular soil. Next, the obtained results up to reaching a certain penetration are represented in Figs 9 and 10.

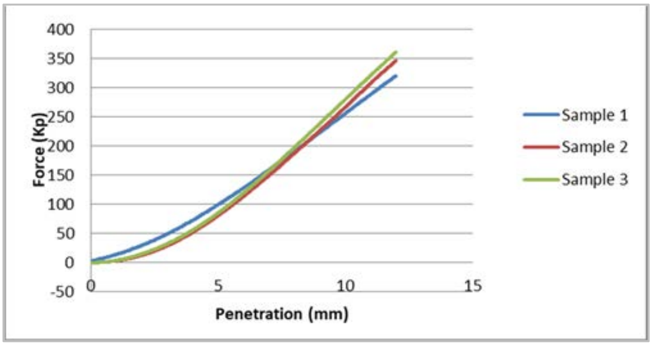

Figure 9: Standard CBR test on Algueña sand.

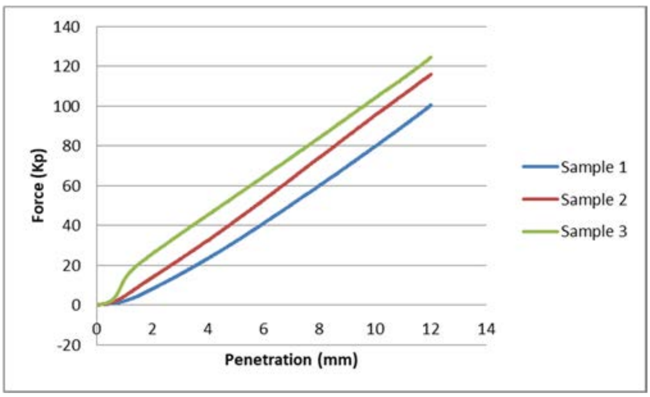

Figure 10: Standard CBR test on Abanilla sand.

Figure 11: Submerged penetration.

2.3.2 CBR modified test
It is the same methodology as that of the previous test, the only difference being that during penetration, the samples were immersed in a cubic container filled with water (Fig. 11). The obtained results up to reaching a certain penetration are represented in Figs 12 and 13.

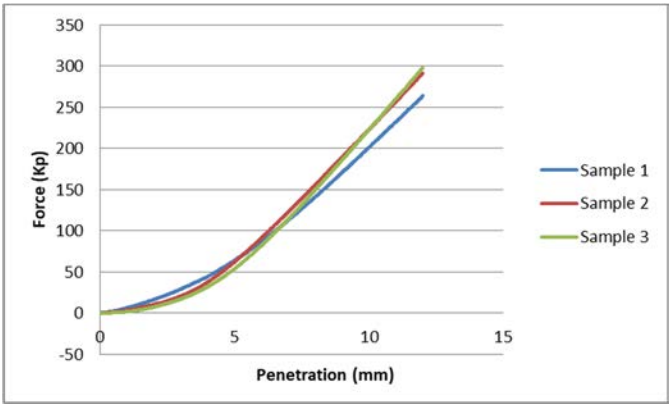

Figure 12: Submerged penetration for samples on Algueña sand.

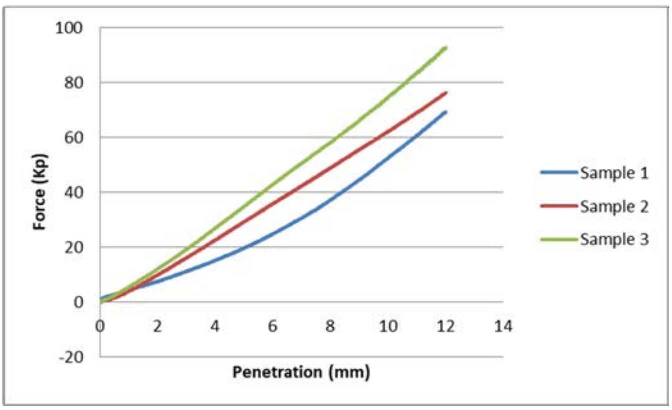

Figure 13: Submerged penetration for samples on Abanilla sand.

3 CONCLUSIONS

The objective of this research was to carry out tests on similar materials to existing ones in the foundation area for offshore wind platforms trying to avoid scour and liquefaction cases. In many cases, the tests carried out in the different research works, including the PISA report involving entities such as the Royal Geographical Society (London), British Petroleum or the Norwegian Institute NGI, have been carried out onshore and on unsaturated samples of soil. Therefore, knowing the behavior of the soil in a submerged situation is a fundamental aspect for evaluating the results obtained on the trials.

In this respect, a modified CBR test that has been carried out allows one to have an approximate idea of the mechanical and resistant behavior of the submerged foundation soil, obtaining the penetration of a piston in a sample of submerged material. The comparison of the results with those obtained in the normalized standard test, would allow one to obtain a relationship between dry and submerged materials, and the penetration values can be estimated without carrying out an "in situ" test on the seabed, but simply with a granulometry of the material and the normalized CBR test, a correction factor would be applied to obtain submerged real values.

The values in Figs 14 and 15 show a decrease in penetration force of 27% and 44%, respectively, to obtain the same value. Although the granulometries and direct cutting tests are similar, although with lower values in the direct cut test on the Algueña sand, there may be some relationship between this value and the one from the submerged penetration test that has been carried out (Figs 16 and 17).

Therefore, it appears that a relationship can be established between the actual submerged values for an offshore foundation and those achieved for a similar material under standard CBR test conditions.

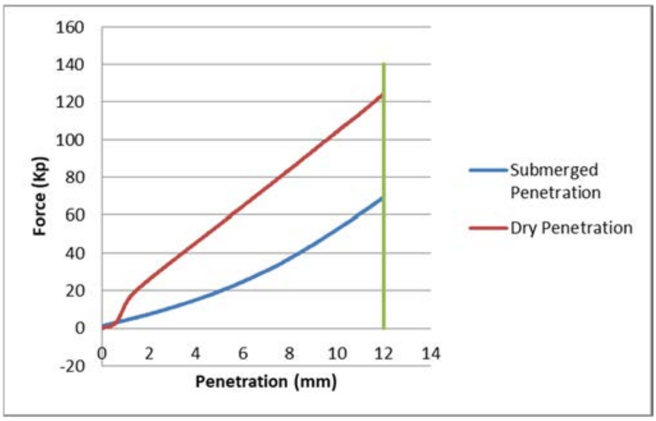

Figure 14: Comparative of penetration (Abanilla sand).

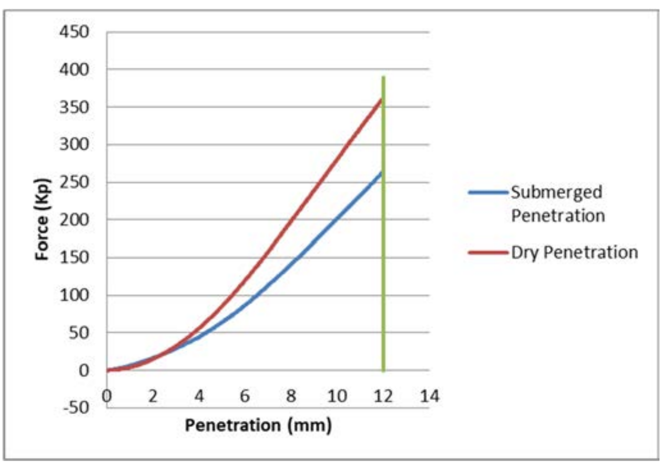

Figure 15: Comparative of penetration for sample 3 (Algueña sand).

Figure 16: Sample after dry penetration.

Figure 17: Sample after submerged penetration.

REFERENCES

[1] Byrne, B.W., McAdam, R., Burd, H.J. & Houlsby, G.T., *PISA: New Design Methods for Offshore Wind Turbines,* 2017.

[2] DNVGL-ST-0126, *Support Structure for Wind Turbines,* 2016.

[3] Lam, I.P.O. & Martin, G.R., Seismic Design of High-Way Bridge Foundations. US Department of Transportation, Report No. FHWA/RD-86/102, 1986.

[4] Papadimitriou, A.G. & Bouckovalas, G.D., Plasticity model for sand under small and large cyclic strains: A multiaxial formulation. *Soil Dyn. and Earthquake Engn.*, **22**(3), pp. 191–204, 2002.

[5] Reese, L., Cox, W.R. & Koop, F.D., Analysis of laterally loaded piles in sand. *Proceedings of the Offshore Technical Conference,* Houston, 1974.

[6] Whitehouse, R.J.S., Sutherland, J. & O'Brien, D., *Seabed Scour Assessment for Offshore Windfarm*, 2006.

[7] Kelly, R.B., Houlsby, G.T. & Byrne, B.W., A comparison of field and laboratory caisson tests in sand and clay. *Géotechnique*, **56**(9), pp. 617–626, 2006.

[8] UNE-EN 933-1 standard, Ensayos para determinar las propiedades geométricas de los áridos (Tests to determine the geometric properties of aggregates).
[9] UNE 103 401 standard, Determinación de los parámetros resistentes al esfuerzo cortante de una muestra de suelo en la caja de corte directo (Determination of the shear resistant parameters of a soil sample in the direct cutting box).
[10] UNE 103 502 standard, Método de ensayo para determinar en laboratorio el índice CBR de un suelo (Test to determine the CBR index of a soil in the laboratory).