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Influence of flow rate in the installation of torpedo pile reduced model in sandy soil experimental field

Influência da vazão na instalação de modelo reduzido de estaca torpedo em campo experimental de solo arenoso

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ABSTRACT: This paper presents the results of installation tests of reduced-scale torpedo pile anchors assisted by the fluidization process created by the circular vertical water jet application. The influence of imposed flow and mass of the anchoring element were evaluated. The prototype analyzed was a 66-ton T66 torpedo pile type. The tests proceeded in an experimental field of sandy soil with models reduced in the length scale 1:12, according to the Froude Number Similarity Law. The flow rates applied were 10.35, 22.81, 30.71 and 41.60 L/min. The results demonstrated similarity with research carried out in laboratory conditions with smaller scales than the one evaluated in this paper. It was observed that the increase in flow caused an increase in the model's penetration depth, as for a given flow, the pile with greater mass has greater penetration. The great contribution of this work was performing tests on a larger scale and proving that results are in line with a large amount of testing on smaller scales, in dimensionless terms. The results indicated that the data obtained in the laboratory (in scales 1:76, 1:67 and 1:50) are still valid for scale 1:12 under the conditions of the present research. The results showed that the fluidization process contributes to increasing the depths of this type of offshore anchoring system and that the correct choice of flow rate and mass of the torpedo pile can improve the installation process.

KEYWORDS: torpedo pile, field tests, offshore anchor, fluidization.

1 INTRODUCTION

The effects of applying water jets to the ground have been studied for decades and related to various fields of engineering such as soil erosion, dredging access channels, lowering bars at channel mouths, petrochemical processes, mining, remediation of contaminated soils (Weisman, *et al*., 1988; Lennon *et al*., 1990, Weisman *et al*., 1994; and Niven & Khalili, 1998). In addition, according to Tsinker (1988), the injection of vertical jets of water can be used as an alternative method, or in conjunction with traditional methods (pile driving, vibrators, pressing, etc.) in the pile installation.

In granular soils, the subject of this research, the fluidization process liquefies the soil by dragging the particles. This fact reduces its resistance. The flow of water must be sufficient to suspend the soil particles, which reduces the contact between the grains and, consequently, their effective tension, which causes the soil to lose its bearing capacity (Leva, 1959, Kunii & Levenspiel, 1969; Mezzomo, 2009; Stracke, 2012; Alsaydalani & Clayton, 2014; Sheplay & Bolton, 2014; Sheplay, 2014; Passini, 2015; Lourenço, 2016). In foundation engineering, this makes it possible for piles to penetrate fluidized soil only by their own weight.

In the field of anchoring offshore structures, several laboratory studies have been carried out over the last few decades on the installation of torpedo piles using water injection (Mezzomo, 2009; Jung, 2012; Stracke, 2012; Passini, 2015; Lorenço, 2016; Passini *et al*., 2017; Passini *et al*., 2018; Mazzuti, 2018; Lourenço *et al*., 2020), as an alternative to the conventional installation method which, according to Fernandes *et al*. (2005), Silva *et al*. (2008), Fernandes et al. (2011), Randolph et al. (2011) and Fernandes et al. (2014), consists of releasing the anchor by free fall at a certain distance from seabed, to gain speed and penetrate through the kinetic energy developed along the way.

The torpedo piles are offshore anchors developed by Petrobras as part of the Deepwater Technology Training Program (PROCAP 2000), with the aim of mooring oil production and exploration equipment and structures in soft clays on the seabed (Morais, 2013), but they have difficulty penetrating granular soil (Medeiros, 2002; Passini, 2015). They are made of metal material in a cylindrical shape, with a conical tip, and may or may not have fins (Medeiros, 2002; Kunitaki, 2006; Costa, 2008; Kawasaki, Aguiar *et al*., 2009; Fernandes *et al*., 2011; Randolph *et al*., 2011; Seckler, 2011; Fernandes *et al*., 2014; and Wang *et al*., 2016 and Bezerra, 2017). Figure 1 shows an example of a torpedo pile (a) and the installation scheme for this type of anchor (b).

The low penetration of these piles in granular soils (sands) results in a load capacity reduction. Another undesirable fact related to the traditional installation method is the non-verticality of the pile after driving (Fernandes *et al*., 2011; Fernandes *et al*., 2014; Lourenço *et al*., 2020 and Camargo, 2020), which also affects the anchoring capacity.

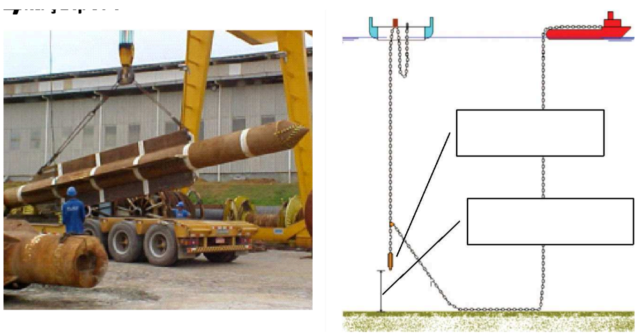

Figura 1: (a) Torpedo pile exemplar and (b) Installation system. Adaptado de Aguiar (2007) e Fernandes et al. (2011).

Within this context, the focus of this study is to continue the work of Passini (2015), Passni & Schnaid (2015), and Passini et al. (2018). While these authors evaluated the behavior of torpedo piles through reduced models on a laboratory scale (1:76 to 1:50) when installed through the fluidization process, this work seeks to evaluate behavior at field scale (1:12). To this end, tests carried out with different jet mass and diameter configurations are presented and discussed, with a staggered and increasing flow rate during installation.

2 EXPERIMENTAL PROGRAM

The site chosen for the tests was the area surrounding the Prof. Dr. Cláudio Renato Rodrigues Dias Geotechnics and Concrete Laboratory (LGC/FURG) on the Carreiros Campus of the Federal University of Rio Grande - FURG. According to Tomazelli & Villwock (2005), the city of Rio Grande, where the Campus is situated, is located on the Rio Grande do Sul Coastal Plain (PCRS) in the Laguna-Barreira IV System, made up of unconsolidated sand sediments, due to its geological formation.

Retzlaff *et al.* (2022) highlight that part of the Campus's buildings received landfill during construction. Likewise, the LGC/FURG has a granular soil fill up to two meters above the natural terrain level.

1.1 *Scale considerations*

The length scale used in this study was 1:12. The other parameters, apart from the geometric ones, were defined according to the Law of Similarity by the Froude number (*Fr*). The Froude number is a dimensionless number proposed by William Froude that represents the ratio between the inertial and gravitational forces of flow, as given by Eq. 1.

$$Fr = \frac{U}{\sqrt{gL}} \tag{1}$$

where U is the fluid velocity in m/s, g is the acceleration of gravity in m/s^2, and L is the characteristic length of the flow in m.

The reduced-scale models had as their prototype the fictitious T66 torpedo pile proposed by Passini (2015). It is a type without fins, with a mass of 66 tons, a length of 17 m, and an external diameter of 1.07 m. Table 1 shows the model's characteristics on a 1:12 length scale, determined by the Froude number similarity criterion and the prototype's properties, as shown in Table 1. It's important to mention that the values adopted for the model were slightly different from those calculated. The practicality of operating the equipment, limitations in the materials market (metallic tubes), and ease of calculation and interpretation of results were important factors in choosing the scale.

Table 1: Characteristics of the length scale models and the torpedo pile used as a prototype.

	Protype (T66)	1:12 model (predicted)	1:12 model (adopted)
L (m)	17,00	1,42	1,50
d_e (m)	1,07	0,089	0,09
m (kg)	66.000	38,19	38,00

A relevant aspect of scale in foundation engineering concerns the relationship between the external diameter of the pile and the diameter of the soil particle - which is one of the effects of scale - because in the model, the diameter of the pile is considerably smaller, meaning that in the prototype scale the sand used in the reduced scale would have a diameter equivalent to a pebble. Another important scaling factor is the effective soil stresses, which are much lower on a reduced scale when compared to the prototype condition.

1.2 *Materials and methods*

Before the fluidization pile installation tests began, tests were carried out to determine the properties of the soil in the experimental field. Sieving, sedimentation, and pycnometer tests determined the granulometric curve and the actual particles specific weight (γ_s) by Brazilian technical standards (NBR 7181/2016 and NBR 6458/2016). Taking samples using crimping cylinders (NBR 9813/1987) made it possible to calculate the apparent natural specific weight of the soil (γ_{nat}) and material extraction to determine various other parameters. Figure 2 shows the soil particle size curve.

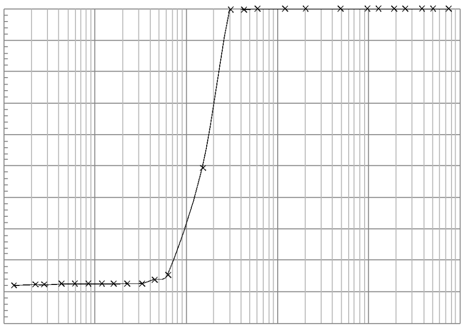

Figure 2: Experimental field soil granulometric curve.

According to Highway Research Board (HRB), the soil classification is A-2-4(0), which defines irregularly graded granular soils, and the group index shows that it has a good bearing capacity. The coefficient of uniformity (*Cu*) identifies the soil as non-uniform, and its specific weight is within range for quartz sand. Table 2 shows the geotechnical properties determined.

Table 2: Soil geotechnical characteristics.

Specific weight of solids - γ_S (kN/m^3)	26,34
Apparent specific weight - γ_{nat} (kN/m^3)	18,19
Dry Apparent specific weight - γ_d (kN/m^3)	17,35

Porosity - η (%)	34,16
Void ratio - *e*	0,52
Maximum void ratio - e_{max}	0,90
Minimum void ratio - e_{min}	0,50
Densidade relativa - D_r *(%)*	95
d_{10} (mm)	<0,0012
d_{30} (mm)	0,100
d_{50} (mm)	0,150
d_{60} (mm)	0,180
d_{95} *(mm)*	0,280
Clay (%)	11
Silt (%)	2
Sand (%)	87
Gravel (%)	0
Uniformity coefficient - C_u	>150
Curvature coefficient - C_c	46
HRB classification	A-2-4(0)
SUCS classification	SC

The effective friction angle (φ') of the soil in the experimental field is 35.53º, determined by the direct shear test. The confining stresses (normal stresses) used were 25 kPa, 50 kPa, 100 kPa, and 200 kPa, with the sample flooded during the test. A speed of 0.10 mm/min was used for the horizontal displacements to ensure that there was not excess pore pressure and to guarantee drained behavior during the test. Figure 3 shows the stress envelope obtained, which shows that the cohesive intercept (c') is null.

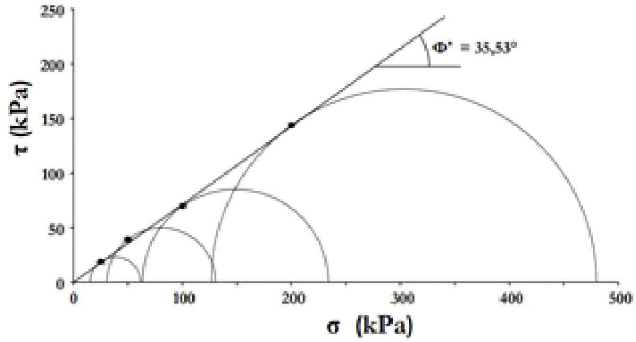

Figure 3: Direct shear test results (stress envelope).

Percussion tests such as the Dynamic Probe Light (DPL) and Standard Penetration Test (SPT) were also performed. The DPL is a test performed with light hand-operated equipment, in which an enlarged base rod penetrates the ground by the impact of a hammer. For every 0.1 m of rod penetration, the number of blows classified as N_{10} is measured, which is a parameter of soil resistance. The SPT is a test widely used in Civil Engineering projects because it has a low cost compared to other field tests. Thus, the decision was to perform a borehole of simple reconnaissance with this test with automatic equipment up to 3 meters deep. Figure 4 shows the results of both trials.

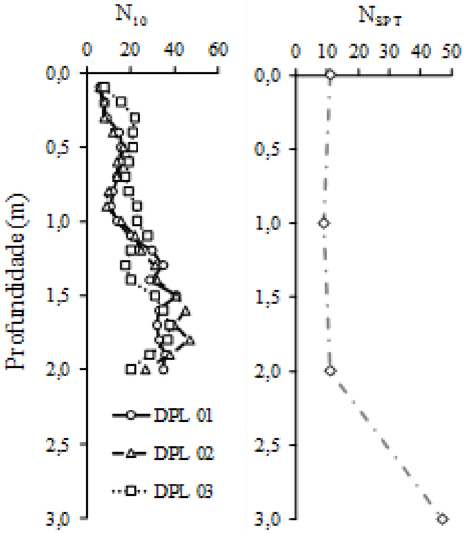

Figure 4: DPL (N_{10}) and SPT results (N_{SPT}: number of blows required to penetrate the last 30 cm).

The soil identified in the assay was fine sand, in the same way as the characterization tests. Compactness ranged from moderately compact to very compact (in the first and second meter, the N_{SPT} was between 9 and 11, and from 11 to 47 in the third and last meter). The assays demonstrated the increase in N_{SPT} with advancing depth is in line with the results of the DPL.

The pile consisted of a metal tube with an external diameter of 90 mm (d_e) and a length of 1500 mm (L) and had a removable tip to allow the introduction of overweights to change the model mass depending on the test configuration. A steel pipe with a diameter of 3/4" runs longitudinally through the pile to carry the water flow to its tip. In addition, the threaded hole at the tip of the pile made it possible to vary the jet's outlet diameter (d_j).

As a laboratory study, it was indicated the influence of mass on the installation depth (Passini, 2015; Passini et al., 2017; and Passini et al., 2018), the pile had configurations of 31 and 42.5 kg in this experiment.

The installation system consisted of a polyethylene water reservoir with a capacity of 1000 L, which serves to store the water pumped by a three-phase electric centrifugal pump with a nominal power of 1.0 HP connected to a frequency inverter, to allow adjusting the flow rate supplied to the system. A 3/4” polyethylene hose carried the water to the tip of the stake. Figure 5 presents the built system. Figure 5 shows the system constructed.

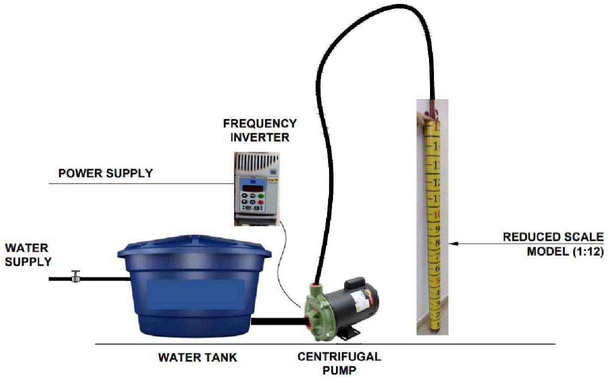

Figure 5: installation system diagram.

Before the test began, the vegetation and the top layer of organic soil were removed to provide the soil interest and pile contact. Then, with the pile in a vertical position, the motor pump was activated, and the process of penetrating the pile by the steel of its own weight began. During the tests, the flow rate was increased in four stages: (i) 10.35 L/min; (ii) 22.81 L/min; (iii) 30.71 L/min; and (iv) 41.60 L/min.

Table 3 shows the characteristics of the two test configurations performed in the present study. The flow stages applied during installation are the same for both, but the jet diameter and the model mass were different.

Table 3: Tests configurations.

Ensaio	d_i (mm)	Massa (kg)
J1M1E	11,25	31,00
J2M1E	22,50	31,00
J1M2E	11,25	42,50
J2M2E	22,50	42,50

3 RESULTS AND DISCUSS

Next, the results obtained will be presented and compared with previous research carried out in the laboratory by Stracke (2012), Passini & Schnaid (2015), Passini (2015), Passini et al. (2017) and Passini et al. (2018).

The technique proposed in this study is the installation of torpedo piles in a reduced model using the soil fluidization technique, using vertical jets of water. The upward flow generated by such jets must be able to offset and drag soil particles, making it liquefied. The consequence of soil liquefaction is the reduction of its bearing capacity, which allows the pile to penetrate.

Figure 6 presents the results obtained for the installation depth (*L*) as a function of the flow rate (Q_0) for the analyzed tests. The graph indicates that penetration increased with the increase in flow, and this behavior was observed for both the 31 kg and 42.5 kg configurations - an increase in the flow of approximately 300% increased penetration by 7300% and 7750% for piles weighing 42.5 kg and 31 kg, respectively.

This figure also shows the influence of mass on depth L, in which the tests with a 42.5 kg configuration penetrated more than the 31 kg, for the same flow rate stage - the tests with the highest mass had an average penetration of 93 and 33% higher than those with the lowest mass, respectively for the 2nd (22.81 L/min) and 3rd (41.60 L/min) stages and flow rate, since for the first stage the average penetrations were the same. The tests were interrupted when the pile completely penetrated, for operational reasons. This slightly impairs the comparison of results for the maximum flow rate of 41.60 L/min, as the tests were completed (motor pump turned off) while the model was still moving downwards.

Figure 7 shows the influence of jet speed, which contains the results for depth L vs. jet exit speed (U_0). The graph shows that the jet speed had little influence on the installation depth for the tests studied.

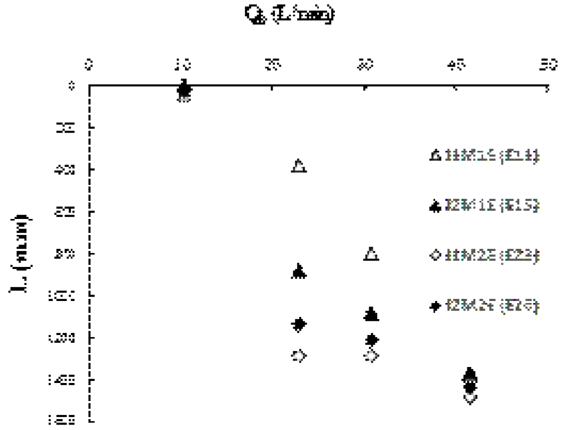

Figure 6: Installation depth versus flow rate.

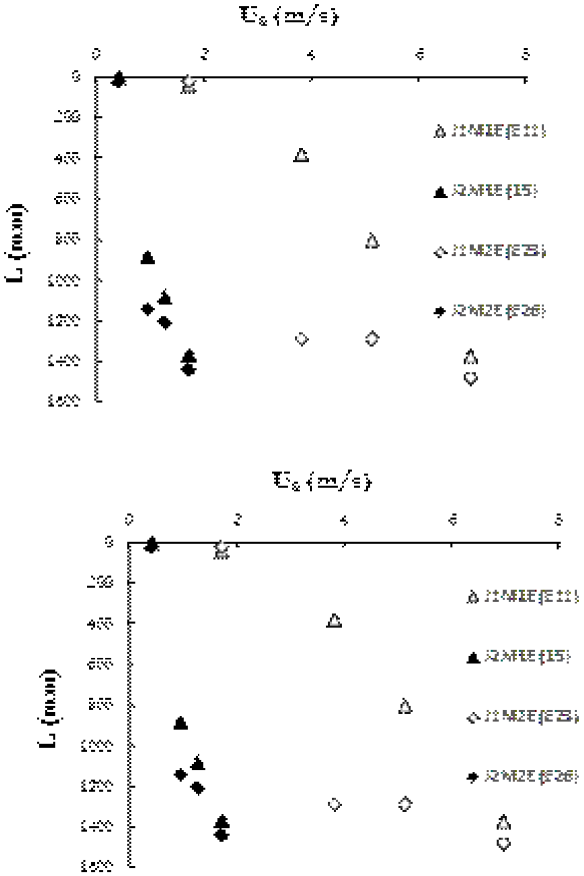

Figura 7: Installation depth versus jet velocity.

The first flow stage (10.35 L/min) was ineffective for penetrating the pile, regardless of the mass configuration (31 or 42.5 kg). For both situations, the average installation depth value was 20 mm.

The results of the laboratory studies carried out by Passini & Schnaid (2015), Passini (2015), Passini et al. (2017), and Passini et al. (2018), using a smaller scale (1:75 to 1:50) in saturated fine sand, also indicated that the installation depth (L) is greater the higher the flow rate (Q_0). These authors analyzed reduced models of the fictitious T66 (66 tons) and T120 (120 tons) torpedo pile prototypes. The results also showed that the flow rate has a greater influence on penetration than the jet velocity, in which the installation depth (L) increased with increasing flow rate (Q_0). Tsinker (1988) and Alsaydalani & Clayton (2014) also suggest that flow rate prevails over the jet exit speed to granular soils.

Stracke (2012) carried out laboratory tests with rods that were introduced into granular soil (saturated fine sand) by an installation mechanism and not by the action of their own weight (suspended rods). In this research, among other things, the critical depth T_3 was verified, at which the flow on the surface of the soil ceases to exist, which, for the author, indicates the end of the fluidization process and, consequently a limit to the penetration of the piles. As in the present study, the author found that the T_3 depth increased as the Q0 flow rate increased, in line with the results obtained in the present study.

To compare the results of this study with the results of studies on smaller scales, a dimensional analysis of the data was necessary. Using Buckingham's Π Theorem, we identified the dimensionless groups $\Pi_1 = L/d_e$ (normalized depth), $\Pi_2 = Q_0/v_f d_{95}$ (flow coefficient), $\Pi_3 = \sigma_{PF}/q_c$ (force coefficient) and $\Pi_4 = d_{95}/d_e$ (scale factor). Where σ_{PF} is the pressure exerted by the tip of the pile (considering a closed tip), v_f is the kinematic viscosity of the fluid, qc is the resistance, and d_{95} is the representative diameter of the soil grains (95% of the grains are smaller than it). Passini (2015) proposes using d95 as the representative diameter, as this would be the most unfavorable case, in which the flow needed to suspend this particle would also suspend all the others smaller than it. That could increase fluidization efficiency.

The results plotted together (this study and Passini, 2015) in the form Π_1 vs Π_2 did not show good agreement. The option was to multiply the dimensionless elements Π_2, Π_3, and Π_4 to form a new dimensionless element called Π_5. Figure 8 shows the results of this research plotted together with the results of Passini (2015).

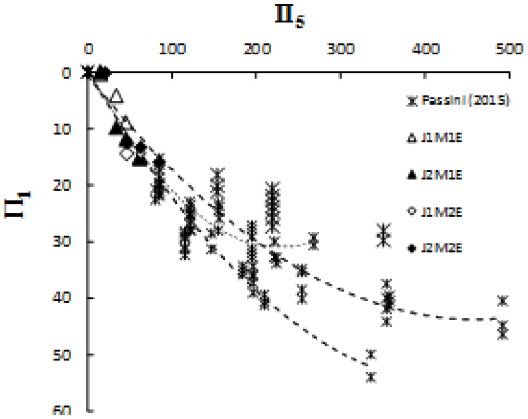

Figure 8: Comparison with Passini (2015) results – normalized data.

The graph indicates good agreement between the results of both surveys. The dimensionless Π_5 considers two important scale factors in foundation engineering: Π_3, which deals with the difference in confining stress (represented by qc), and Π_4, which deals with the difference in the proportion of the soil grain size about the pile diameter at different scales.

It is important to note that the tests carried out in this study did not faithfully represent laboratory conditions because the experimental field soil was not saturated. The original granular soil fluidization procedure consider saturated soils, but it could be applied to unsaturated soils (fine and medium sands) by creating a "recharge zone" from the water table, according to Niven & Khalili (1998). This condition could positively influence the penetration of the piles into the soil, due to the reduction in effective stress.

4 CONCLUSIONS

This article presents the partial results of penetration tests of torpedo anchors on a reduced scale through the fluidization of the soil by applying vertical water jets. The tests presented revealed that the application of water jets to granular soils proved to be effective for the installation of 1:12 scale models.

For the tests carried out, the results demonstrated a gain in installation depth with the rise in flow. Increasing the mass of the model also led to an increment in penetrations. These behaviors were the same as those found in laboratory research on smaller scales than 1:12. However, the speed of the jet had no significant influence on the penetration depth, also in line with the literature. For this reason, the present study does not make any progress in this area.

The results showed a similar trend to previous research data on a smaller scale, for the configurations tested and the type of soil in the experimental field when treated in a normalized way with the proposed dimensionless variables.

4 REFERÊNCIAS

Aguiar, C. S., Sousa, J. R. M., Ellwanger, G. B., Porto, E. C., Medeiros JR, C. J., Foppa, D. 2009. Undrained load capacity of torpedo anchors in cohesive soil. *Proceedings of the OMAE Conference*, Hawaii.

Alsaydalani MOA, Clayton CRI. 2014. Internal fluidization in granular soils. *J Geotech Geoenviron Eng.* 140(3):1-10. doi: 10.1061/1943-5606.0001039.

Brazilian Association of Norms Techniques. ABNT NBR 6458: Gavel grainS retained on the 4.8mm mesh sieve - determination of the bulk specific gravity, fo the apparent specific gravity and water absorption. Rio de Janeiro (RJ): ABNT; 2016.

Brazilian Association of Norms Techniques. ABNT NBR 7181: Soil – Grain size analysis. Rio de Janeiro (RJ): ABNT; 2016.

Bezerra, C. M. N. 2017. Numerical analysis of torpedo anchor penetration modeled by integral of pressures. M.Sc. Thesis. Federal University of Rio de Janeiro. Rio de Janeiro, Brazil. In Portuguese.

Camargo, K. R. 2020. Watter jetting in fine soils – laboratorial and field tests Ph.D Thesis. Federal University of Rio Grande do Sul. Rio Grande do Sul, Brazil. In Portuguese.

Costa, R. G. B. 2008. Análise paramétrica das condições de ancoragem de plataformas offshore utilizando estacas torpedo a partir de modelos em elementos finitos. M.Sc. Thesis – Federal University of Rio de Janeiro (COPPE/UFRJ), Rio de Janeiro, Brazil, 109p. In Portuguese.

Fernandes, A. C. 2014. Scientific and operational consequences of non conventional model testing in deepwater ocean basins. *Marine Systems & Ocean Technology* 9, 1, pp. 59—69.

Fernandes, A. C., Araújo, J. B., Diniz, R., Santos, M. F., Almeida, J. C. F., Matos V. 2005. Hydrodynamic aspects of the torpedo anchor installation. *24th International Conference on Offshore Mechanics and Arctic Engineering (OMAE 2005)*.

Fernandes, A. C., Sales, J. S., Silva, D. F. C., Diederichsa, D. R. 2011. Directional stability of the torpedo anchor pile during its installation. *The IES Journal*. 4, pp 180–189.

JUNG, J. G., 2012,Study of water jets in clay and its application to offshore foundation engineering. M.Sc. Thesis – Federal University of Rio Grande do Sul (UFRGS). Rio Grande do Sul, Brazil, 178p. In Portuguese.

Kawasaki, P. Y. 2010. Analysis of ocean platform anchoring lines considering several sections and the buried section of the line. Projeto de Graduação. Federal University of Rio de Janeiro. Rio de Janeiro, Brazil. In Portuguese.

Kunii, D., Levenspiel, O. 1969. *John Wiley & Sons.* Nova Yorque. Fluidization Engineering. 534p.

Kunitaki, D. M. K. N. 2006, uncertainty treatment in the dynamic behaviour of torpedo pile for floating systems anchoring in offshore petroleum exploitation. M.Sc. Thesis. Federal University of Rio de Janeiro. Rio de Janeiro, Brazil. In Portuguese.

Lennon GP, Chang T, Weisman RN. 1990. Predicting incipient fluidization of fine sands in unbounded domains. *J Hydraul Eng.* 116(12):1454-67. doi: 10.1061/(ASCE)0733-9429(1990)116:12(1454).

Leva, M. 1959. *MCGraw-Hill Book Co.* New York. *Fluidization.*

Lourenço DE, Schnaid F, Schettini EBC. 2020. Model pile installation by vertical water jet in clay. *J Offshore Mec Artic Eng.* ASME. 144:045001-1-9. doi: 0.1115/1.4046169.

Lourenço, E.D. 2016. Hydro jetting in clay soils. Ph.D. Thesis. Federal University of Rio Grande do Sul. Rio Grande do Sul, Brazil. In Portuguese.

Mazutti, J. H. 2018. Study of the shaft resistance in pullout tests of model piles installed by fluidization in sand. M.Sc. Thesis. Federal University Rio Grande do Sul. Rio Grande do Sul, Brazil. In Portuguese.

Medeiros JR., C. J. 2002, Low cost anchor system for flexible risers in deep waters. Em: Proceedings of the Annual Offshore Technology Conference, Paper 14151, 6–9 May, Houston, USA, 5p.

Mezzomo, S. M. 2009. Study of fluidization using water jets in sand. M.Sc. Thesis. Federal University of Rio Grande do Sul. Rio Grande do Sul, Brazil. In Portuguese.

Morais J. M. 2013. Deep water Petroleum: a technological history of Petrobras in offshore exploration and production. Brasília : Ipea : Petrobras. In Portuguese.

Niven RK, Khalili N. 1998. In situ multiphase fluidization ("upflow washing") for the remediation of hydrocarbon contaminated sands. *Can Geotech J.* 35:938-60. Doi: 10.1139/t98-067

Passini LB, Schnaid F, Rocha MM, Moller SV. 2018. Mechanism of model pile installation by water jet fluidization in sand. *JCR Ocean Eng.* 170:160-70. doi: 10.1016/j.oceaneng.2018.10.017.

Passini, L. B. 2015. Installation and axial load capacity of fluidized model piles in sandy soils. Ph.D. Thesis. Federal University of Rio Grande do Sul. Rio Grande do Sul, Brazil. In Portuguese.

Passini, L.B.; Schnaid, F.; Salgado, R. 2017. Experimental study of shaft resistance of model piles in fluidized and nonfluidized sand. *Journal of Offshore Mechanics and Artic Engineering*, v. 139, 052001-1-052001-1.

Randolph, M. F., Gaudin, F., Gourvenec, S. M., White, D. J., Boylan, N., Cassid, M. J. 2011. Recent advances in offshore geotechnics for deep water oil and gas developments. *Ocean Engineering* 38 (2011) 818–834. doi:10.1016/j.oceaneng.2010.10.021.

Retzlaff, A. S. Alonso, V. V. Camargo, K. R., Gonzales, R. R. Bastos, C. A. B. 2022. Construction and interpretation of a GIS of simple recognition surveys with water circulation carried out with FURG. *Brazilian Congress on Soil Mechanis and Geotechnical Engineering,* São Paulo, Brazil. In Portuguese.

Seckler, C. S. 2011. A methodology based on inspection and retroanalysis for the verification and adjustments of mooring systems of offshore oil floating production units. M.Sc. Thesis. Federal University of Rio de Janeiro. Rio de Janeiro, Brazil. In Portuguese.

Shepley P, Bolton MD. 2014. Using water injection to remove pile base resistance during installation. *Can Geotech J.* 51:1273-83. doi: 10.1139/cgj-2013-0240.

Shepley P. 2015. Optimisation of waterinjection nozzles to aid pile jacking. *Geotech Eng.* 168:257-66. doi: 10.1680/geng.14.00072.

Silva, U. A. DA. 2008. Driveability analysis of torpedo piles. Monografia de conclusão de curso. Federal University of Rio de Janeiro (COPPE/UFRJ), Rio de Janeiro, Brasil, 51p. In Portuguese.

Stracke, F. 2012. Fluidização de solo arenoso associado à injeção de agente cimentante para ancoragem de estruturas offshore. Dissertação de Mestrado. Universidade Federal do Rio Grande do Sul.

Tomazelli L. L. e Vilwock J. A. 2005. Geological Mapping of Coastal Plains: the Example of the Rio Grande do Sul Coast. *Gravel.* 1678-5975. (3), 109-115. In Portuguese.

Tsinker, G. P. 1988. Pile jetting. *Journal of Geotechnical Engineering*, ASCE, 114(3): 326–334.

Wang C, Wang Y, Peng C, Meng X. 2016. Two-fuid Smoothed Particle Hydrodynamics simulation of submerged granular column collapse. *Mech Res Commun.* 79:15-23. doi: 10.1016/j.mechrescom.2016.12.001.

Weisman RN, Lennon GP. 1994. Design of fluidizer systems for coastal environment. *J Waterway, Port, Coastal, Ocean Eng.* Sep;120(5):468-87. doi: 10.1061/(ASCE)0733-950X(1994)120:5(468).

Weisman RN, Lennon, GP, Roberts EW. 1988. Experiment on fluidization in unbounded domains. *J Hydraul Eng.* 114(5):502-15. doi: 10.1061/(ASCE)0733-9429(1988)114:5(502).

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