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Pile test database on centrifuged models: tension loading for floating wind turbine anchor

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ABSTRACT: The memory of series of centrifuge tests performed in Nantes is being to come accessible through an open database. The main parameters of the database (piles-anchors in sand) which includes 190 tests on small-scale centrifuged models of piles subjected to tension loading are presented: density, saturation, installation, embedment and loadings (monotonic, cyclic or combined).

Keywords: Close-Ended Pile; Helical Pile; Tension; Sand; Centrifuge Models.

1 INTRODUCTION

As part of the energy transition and the development of marine renewable energies, the Ifsttar began in 2017, in response to a call for proposals from the Weamec, the REDENV-EOL research programme, which deals with the Reduction of the Environmental Impact of Floating Wind Turbine anchored with Pile Foundations. The idea here is to reduce the length of the anchor lines, favouring the tension lines that make the anchor pile work in traction, mobilizing the vertical resistance of the pile-soil interaction.

190 tensile tests on close-ended cylindrical piles or helical piles have been carried out and grouped in a database, which is presented here. Four smooth piles (Figure 1) installed in flight at 100g in Fontainebleau Sand NE34, dense or loose, dry or saturated, are then subjected to vertical tension. Five single helix helical piles (Figure 1) of different diameter are installed in flight by screw driving at 10 different relative depths, in Hostun sand HN38, dense or loose, dry or saturated. The installation forces are measured. The helical piles are subjected to monotonous, cyclic or even monotone post-cyclic loads. All these tests are grouped in a database whose detailed characteristics are presented here.

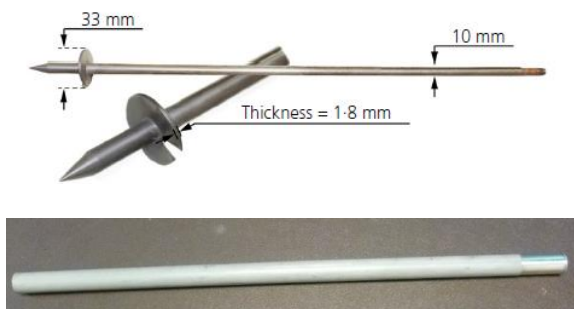


Figure 1 Model piles. Example of single helical steel helical pile (left, Schiavon et al. 2018) and closed cylindrical aluminum pile ($D=18\text{mm}$, length 250mm , El Haffar, 2018).

2 MATERIALS

The experiments were conducted in the geotechnical centrifuge of the Univ. Gustave Eiffel. These are models of smooth piles installed in sand that is usually very dense, in flight (that is, under conditions of stress similar to those observed in real size), and then subjected to a coaxial tensile load. Figure 2 shows the example of a test on a closed cylindrical pile ($D=18\text{mm}$) in saturated dense sand, including the driving phase (with a hydraulic jack in flight) and then the loading phase in tension. The procedure is detailed in El Haffar et al. (2017).

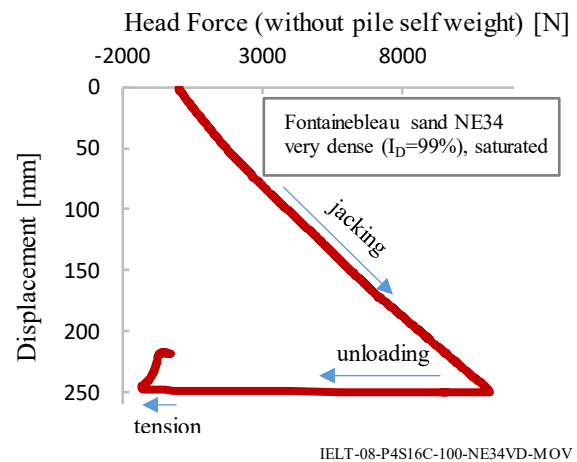


Figure 2 Displacement stress curve (model sizes) of a closed cylindrical smooth pile installed in very dense saturated sand and then loaded in traction ($D=18\text{mm}$, according to El Haffar, 2018).

For helical piles, the procedure, described by Schiavon et al. (2018), includes a controlled pole movement and rotation installation phase, followed by monotonous or cyclic loading phases (Figure 3).

Table 1 presents the parameters of geometry, scale (a scale model $1/N$ is tested under a centrifugal acceleration of N times the acceleration of earth gravity), and loading applied. Some tests were carried out in dry sand and others in saturated sand.

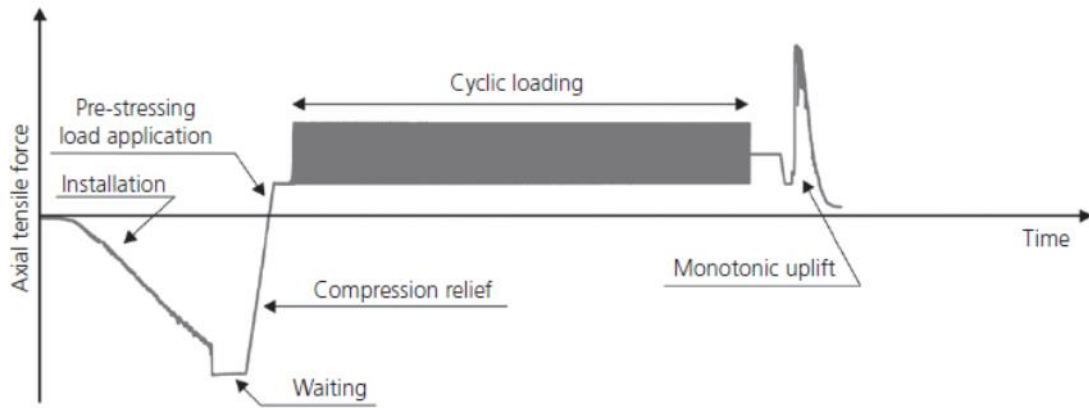


Figure 3 Example of the evolution of axial force versus time of a helical pile test, including installation, cyclic loading, and post-cyclic monotone phases (Schiavon et al., 2018).

Table 1 Distribution of geometries, densities and loading types of the 190 tests.

Pile			Scale	Sand	Number of tests		Loading				
Type	D [mm]	Relative depth z/D			dry	saturated	m	c	m-c	m-c-pc	c-pc
Close ended	12	20.83	1/100	NE34	1 MD	1+1 MD	3	0	0	0	0
	14	17.86	1/100	NE34	1+1 MD	1+1 MD	4	0	0	0	0
	16	15.63	1/100	NE34	1+1 MD	1+1 MD	4	0	0	0	0
	18	13,89	1/100	NE34	1+1 MD	1+1 MD	4	0	0	0	0
Mono-helix d=10mm	40	6	1/10	HN38	4	9	0	0	0	6	7
	33	6 - 7.4 - 7.8 - 8	1/10	HN38	20	41	5	10	1	7	38
	25	6 - 8 - 9.6 - 10 - 12 - 14	1/10	HN38	12	36	3	0	1	17	27
	18	6 - 8 - 10 - 10.5 - 13.3	1/10	HN38	15	17	10	0	7	11	4
	13	6 - 8 - 18.5	1/10	HN38	5	3	4	0	3	1	0
Mono-helix instrumented d=10mm	33	7.4	1/10	HN38	13	0	0	0	0	0	13

MD : medium dense / D : helix or cylindrical pile diameter / d : diameter of the helical pile's shaft
m : monotonic initial / c : cyclic / pc : monotonic post-cyclic

The helix geometry is specified in Table 2 (Schiavon, 2018). The relative depth of the tip of the closed cylindrical piles takes four different values shown in a balanced way, while 11 helix depths have been tested, four of them representing almost the entire population (Figure 4). The relative depths tested make it possible to scan several configurations, but also, for some of them to test different combinations and loading intensities.

Table 2 Helical pile's geometry

Helical pile	D/d	D (mm)	d (mm)	t _h (mm)	φ _h (°)
HA13	1.3	13	10	1.0	6
HA18	1.8	18	10	1.0	6
HA25	2.5	25	10	1.5	6
HA33	3.3	33	10	1.5	6
HA40	4.0	40	10	2.0	6

D : Helix's diameter / d : shaft's diameter / t_h : Helix's thickness / φ_h : Helix's angle

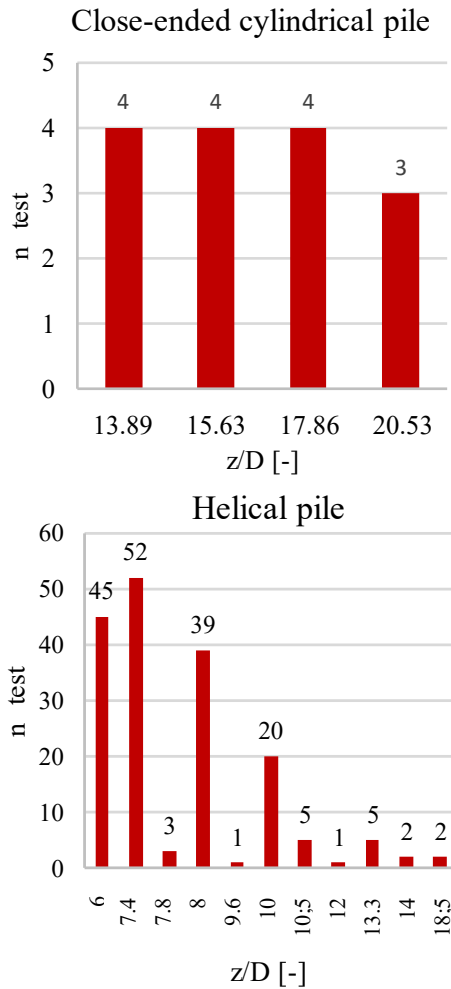


Figure 4 Relative depth: Close-ended cylindrical piles (top) and buried helical pile's helix (bottom).

3 CYCLIC LOADING

Cyclic loads are controlled in force and take the form of a temporal sinus. Thus, the load is characterized by its frequency and by two parameters: the mean vertical load V_m and the cyclic half-amplitude V_c (Figure 5a). By introducing the ultimate tensile V_{ut} load, we can represent in an dimensionless diagram all the cyclic loading conditions of the experiments (Figure 5b).

Most cyclic tests (92%) follow tension loads ($V_m > V_c$) and some alternate loads are also included. The distribution of the stress types according to the V_c/V_m ratio (Figure 6) shows a wide variety, as well as 3 predominant values which correspond to an alignment of the test points in Figure 5 according to a linear function (for example, with a slope of 0.5).

One of the objectives of studying the behaviour of a cyclically charged pile is to identify the movements accumulated during the cycles that could potentially lead to failure. The number of cycles applied varies greatly depending on the

intensity of the load, between 3 and 10,000 cycles. The maximum observed displacement reaches 1.5D and the SLS criterion used corresponds to a cumulative displacement of 0.1D. The frequency of the sine signal applied is not the parameter studied in priority, the idea being to be within the framework of quasi-static loads. Only 3 frequencies (model size) were tested: 0.3Hz (56% of cases), 0.4 Hz (1%) in saturated sand and 1Hz (43%) in dry sand.

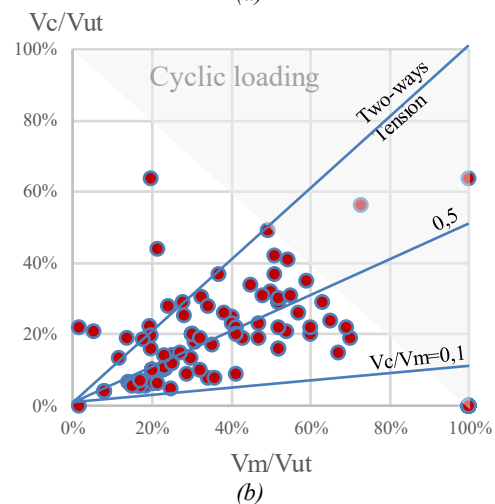
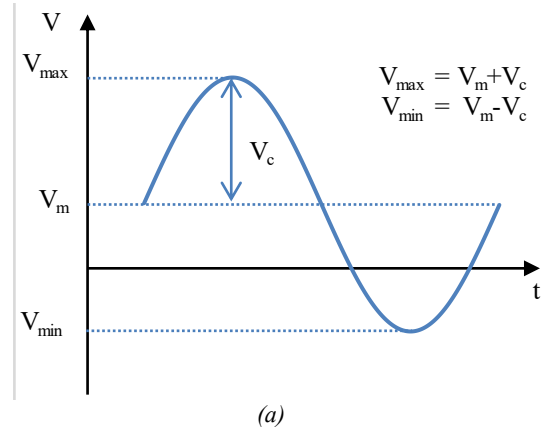


Figure 5 Cyclic loads: shape of sinusoidal loading (a) and combinations of the different loads applied (b).

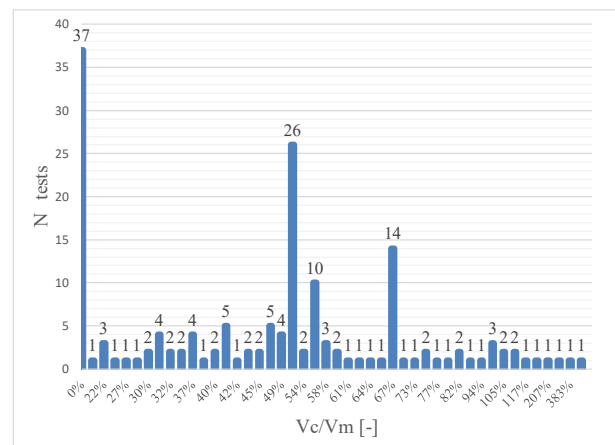


Figure 6 Distribution of the cyclic load to average load ratio

4 DATABASE STRUCTURE AND NUMERICAL DATA

The structuring of the base (Figure 7) uses other files containing detailed information which are not in the data file *stricto sensu*, such as the characteristics of the soil used, the nature of the experimental campaign, the properties of the pile, the experimental assembly or loading conditions.

The file of each test follows a particular organization, starting with its name, which follows a specific nomenclature (Figure 8). The termination depends on the type of software used to edit the data (e.g. .txt or .xls). Each file contains in the first column the time, then in the other columns the recorded data.

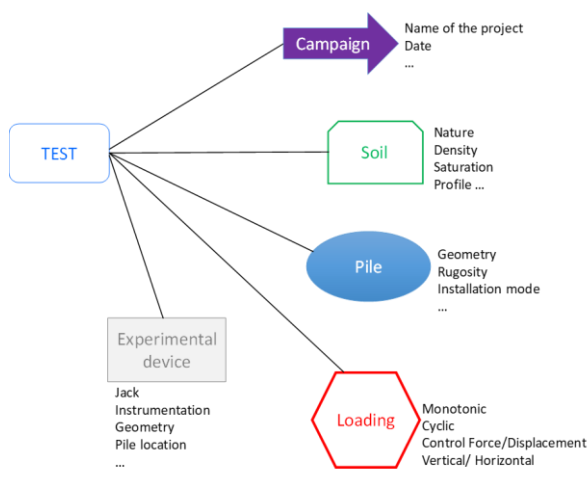


Figure 7 Database structure

□	First name's initial
□□□	Name's initial of the researcher
-	
□□	N° container
-	
□□□□□□	Type of pile
-	
□□□	g-level
-	
□□□□□□	Soil
-	
□□□	Loading

Figure 8 Nomenclature of the files' name. Each rectangle □ corresponds to a character

The file corresponding to the test presented on figure 2 is named IELT-08-P4S16C-100-NE34VD-MOV corresponding to the following informations:

- Ismat **EL Haffar** Thèse
- Container (or strongbox) n°**08**
- Pile n°**P4**, Smooth, **16mm** in diameter, Closed at the tip

- Centrifuge acceleration of **100g** corresponding to a test at scale 1/100
- Fontainebleau sand **NE34 Very Dense**
- **Monotonic Vertical Loading**

The data for each test of the database will be recorded in a « dataverse » system, with a free access for tests already published, and identified with a DOI number: https://research-data.iftstar.fr/dataverse/piles-anchors_in_sand.

5 CONCLUSIONS

An overview of a new database of experiments carried out in the geotechnical centrifuge of the Université Gustave Eiffel, Campus de Nantes, has been presented here. All the tests carried out relate to traction loading. This base includes closed cylindrical piles under monotonous load and mono-helical piles under monotonous or cyclic loads. All model piles are installed in macro gravity.

6 ACKNOWLEDGEMENTS

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