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## Dataset for centrifuge modelling of laterally monotonic loaded monopiles in saturated dense sand

Zhong-Sen Li<sup>1\*</sup>, Matthieu Blanc<sup>2</sup>, Luc Thorel<sup>3</sup>

- <sup>1</sup> Department of Civil Engineering, Aalto University, Otaniemi, Finland; formerly at Laboratory of Geotechnical Centrifuges, Department GERS, University of Gustave Eiffel, Bouguenais, France; Orcid:0000-0002-3380-4000
- <sup>2</sup> Laboratory of Geotechnical Centrifuges, Department GERS, University of Gustave Eiffel, Bouguenais, France; ORCID: 0000-0003-0603-487X
- <sup>3</sup> Laboratory of Geotechnical Centrifuges, Department GERS, University of Gustave Eiffel, Bouguenais, France; ORCID: 0000-0002-0218-4144
- \* Zhongsen.li@aalto.fi, +358 50 477 7614, 'twitter: @ZhongsenL'

### Keywords

Offshore wind turbine foundation; Soil-pile interaction; Tension-compression asymmetry; Fibre Bragg gratings

### Abstract

The presented dataset was collected in seven centrifuge tests, specifically designed for modelling the lateral response of offshore monopiles in dense sand. Two model piles with outer diameter  $D = 50$  mm were loaded laterally at  $100\times g$ . The embedding depths were  $3D$ ,  $5D$ ,  $7D$  and  $9D$ , with load eccentricity of 5, 10 and 15. Fibre Bragg gratings (FBGs) were used to measure the tensile and compressive strains of the monopiles. The raw data obtained from different sensors during the tests and the analysed data (e.g. soil reaction, pile deflection) are included in separate editable files, enabling future reuse and development of the experimental results.

### Specifications table

|                              |                                                                |
|------------------------------|----------------------------------------------------------------|
| <b>Subject</b>               | <b>Engineering:</b> Civil and Structural Engineering           |
| <b>Specific subject area</b> | Geotechnical engineering for offshore wind turbine foundations |
| <b>Type of data</b>          | Table                                                          |

|                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|---------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>How the data were acquired</b>     | The raw data were acquired via three types of sensors: a load cell that measures the applied lateral force (range: 0-5 kN; accuracy: 0.1 N), four laser sensors and an electric actuator measuring the lateral displacement of the piles (range: 0-120 mm; accuracy: 0.02 mm) and FBGs integrated optic fibres that measure the normal strains of the piles. Data acquisition was run in software (Catman), where measurements from the sensors were saved into comma-separated value (CSV) files every 0.05 or 0.02 second. |
| <b>Data format</b>                    | Raw<br>Filtered<br>Analysed                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| <b>Description of data collection</b> | The tests were performed in a large-beam centrifuge (5.5 m in radius) at the University of Gustave Eiffel. The operational gravity acceleration was $100\times g$ for all the tests. The sand sample has a homogeneous density of $1677 \text{ kg/m}^3$ (i.e. 81% in relative density) and was saturated with tap water.                                                                                                                                                                                                     |
| <b>Data source location</b>           | <ul style="list-style-type: none"> <li>• Institution: University of Gustave Eiffel</li> <li>• City: Bouguenais</li> <li>• Country: France</li> <li>• Latitude and longitude (and GPS coordinates, if possible) for collected samples/data: (47.157137891245995, -1.6387849924481603)</li> </ul>                                                                                                                                                                                                                              |
| <b>Data accessibility</b>             | Repository name: Mendeley Data<br>Data identification number: 10.17632/mkmv4mdxxs.2<br>Direct URL to data: <a href="https://data.mendeley.com/datasets/mkmv4mdxxs/2">https://data.mendeley.com/datasets/mkmv4mdxxs/2</a>                                                                                                                                                                                                                                                                                                     |
| <b>Related research article</b>       | Li, Z.S., Blanc, M., Thorel, L., Effects of embedding depth and load eccentricity on lateral response of offshore monopiles in dense sand: a centrifuge study. Géotechnique. Ahead of Print, pp. 1-15.<br><a href="https://doi.org/10.1680/jgeot.21.00200">https://doi.org/10.1680/jgeot.21.00200</a>                                                                                                                                                                                                                        |

#### Value of the data

- The data provide first-hand centrifuge modelling results on laterally loaded monopiles. The high-quality results will be useful to be conjunctly analysed with the reduced-scale laboratory tests and full-scale field tests to develop new design codes for offshore wind turbine foundations.
- Asymmetry in tension and compression of laterally loaded monopiles (often ignored in previous studies) was detected using a state-of-the-art strain measuring technique, i.e. FBGs. Geotechnical researchers and offshore wind turbine practicing engineers can use the data as a reference to compare their test results.

### Data description

Data in this paper are included in four excel files. File '01 Raw.xlsx' presents the data acquired during lateral loading and scaled up to prototype scale according to the similitude law (Table 1), where  $N$  is the gravity acceleration and equals to 100 in this study. The excel file consists of seven sheets: sheets number 1-4 correspond to tests at constant load eccentricity (i.e.  $L_e/D = 10$ ), sheets number 4-6 are tests at constant embedding depth (i.e.  $L/D = 5$ ) and sheet number 7 is a repeat of test #1 because one of the optic fibres was lost the connection with the interrogator. In each sheet, one column represents one specific parameter (e.g. time, force, FBGs peak wavelength and pile displacement) that measured by the sensors when lateral loading was launched.

| Parameter                 | Measuring instrument | 1/ $N^{\text{th}}$ centrifuge model (raw data) | Prototype             |
|---------------------------|----------------------|------------------------------------------------|-----------------------|
| Time                      | Catman software      | $T$                                            | $T^* = T$             |
| Force                     | Load cell            | $F$                                            | $F^* = F \times N^2$  |
| Peak wavelength           | FBGs                 | $\lambda$                                      | $\lambda^* = \lambda$ |
| Pile lateral displacement | Laser sensor         | $y$                                            | $y^* = y \times N$    |

Table 1 Scaling up the centrifuge model (raw data) to the prototype

File '02 Raw\_Thinned.xlsx' presents the data selected by the authors based on the bending moment at the ground ( $M_g$ ). We first find the FBGs that corresponds to the ground level (e.g. FBGs #5 for Test 2) and calculate the ground-level bending moment with the following formula:

$$\varepsilon = \frac{\Delta\lambda}{0.78\lambda} \quad (\text{Eq. 1})$$

$$M = \frac{EI(\varepsilon_T - \varepsilon_C)}{2} \quad (\text{Eq. 2})$$

where  $E$  [Pa] is the Young's modulus of the monopile,  $I$  [m<sup>4</sup>] is the moment of inertia of the monopile,  $D$  [m] is the outer diameter of the monopile,  $\lambda$  [m] is the peak wavelength, and  $\varepsilon_T$  and  $\varepsilon_C$  are the calculated tensile and compressive strains, respectively. Then, we find the indices for which the ground-level bending moments are integers (e.g. 200, 400, 600 and 800 MN.m for Test 2). With the indices, we selected four (five for some tests) rows in file '01 Raw.xlsx' so that these representative loading moments can be analysed succinctly in the next steps.

File '03 Calculated\_Strain' presents the calculated normal strains at different embedding depths. The profiles of the normal strain can be plotted, and an example is shown in Figure 1 with data from Test #2.

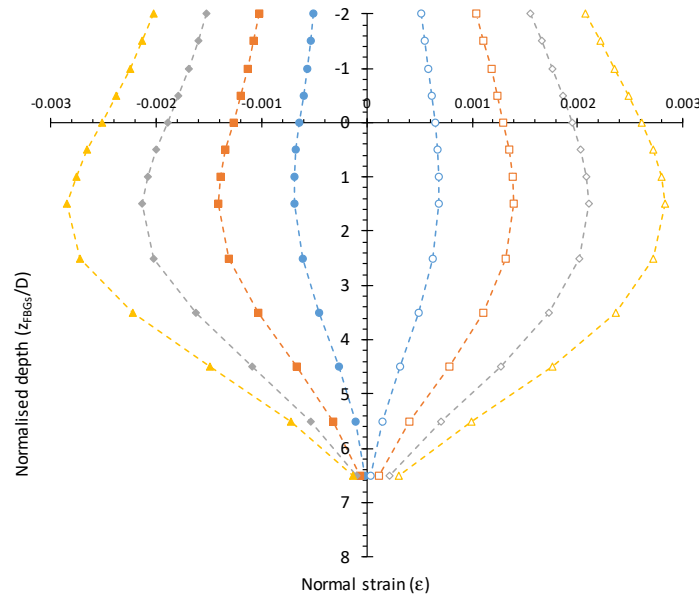


Figure 1 Profile of the normal strain for Test 2 ( $L/D = 7$ ,  $L_e/D = 10$ )

File '04 Calculated\_DeflectionReaction' presents the calculated data for the normalised pile deflection  $y/D$ , pile rotation  $\theta$ , bending moment  $M$ , shear force  $T$  and soil reaction  $P$ . The methodology and workflow of obtaining this data were described in detail elsewhere [1]. The profiles of  $y/D$ ,  $\theta$ ,  $M$ ,  $T$  and  $P$  can be also plotted, and, similarly, an example is shown in Figure 2 with the data from Test 2.

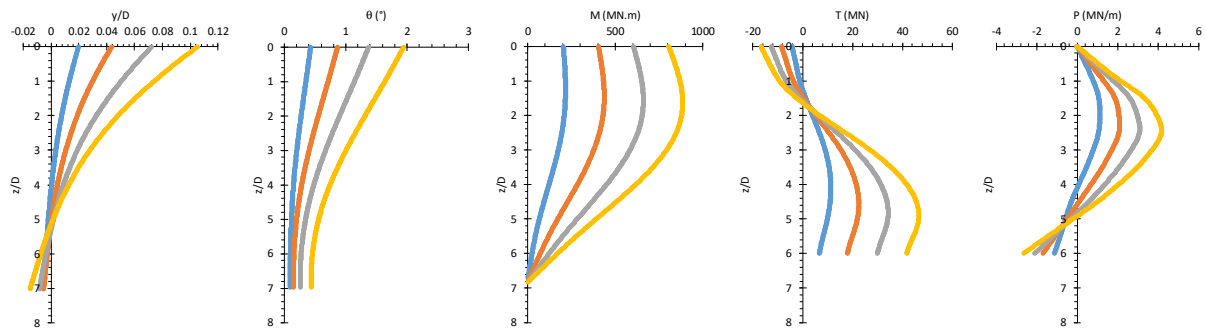


Figure 2 Profiles of the pile deflection  $y/D$ , rotation angle  $\theta$ , bending moment  $M$ , shear force  $T$  and soil reaction  $P$  for Test 2 ( $L/D = 7$ ,  $L_e/D = 10$ ; reproduced from Fig. 7 of [1])

## Experimental design, materials and methods

Two circular, open-ended and aluminium piles, with dimension and mechanical behaviour presented in Table 2, were instrumented with fibre Grating sensors (FBGs). Prior to testing in the centrifuge, the two instrumented piles had been calibrated by applying a set of incremental lateral loadings at  $1 \times g$ . The calibrating results are now available in [2].

| Parameters of the pile |           | 1/N <sup>th</sup> centrifuge model | Prototype |
|------------------------|-----------|------------------------------------|-----------|
| Outer diameter         | $D$ (m)   | 0.05                               | 5         |
| Inner diameter         | $d$ (m)   | 0.045                              | 4.5       |
| Young's modulus        | $E$ (GPa) | 74                                 | 74        |

|                   |                          |                        |                      |
|-------------------|--------------------------|------------------------|----------------------|
| Flexural rigidity | $EI$ (N·m <sup>2</sup> ) | $7.8 \times 10^3$      | $7.8 \times 10^{11}$ |
| Length            | $L$ (m)                  | 0.15, 0.25, 0.35, 0.45 | 15, 25, 35, 45       |
| Load eccentricity | $L_e$ (m)                | 0.25, 0.50, 0.75       | 25, 50, 75           |

Table 2 Details of the pile in model and prototype scale

The dry Fontainebleau NE34 sand was pluviated into a strongbox of 1.2 m in length, 0.8 m in width and 0.72 m in height. A homogeneous sand sample with density of 1677 kg/m<sup>3</sup> (81% in relative density) was reconstructed after removing the upper sand layer by mean of vacuum cleaner. Since the Fontainebleau sand is a poorly graded material, saturation was reached by inputting water from the bottom with the help of a small differential water head (Figure 3).



Figure 3 Preparation of the sand specimen: (a) pluviation; (b) saturation

The instrumented model piles were pushed into the afore-prepared sand specimen at 1×g with a hydraulic actuator. The velocity was 1 mm/s and the attained depths were 150, 250, 350 and 450 mm (Figure 4a).

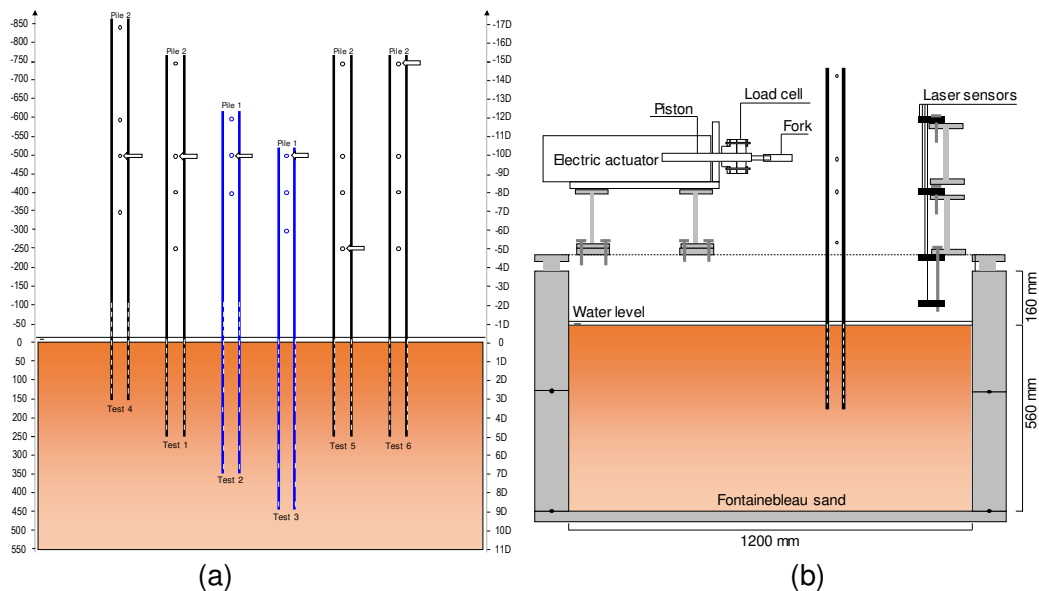


Figure 4 Configuration of the test: (a) pile embedding depths and loading eccentricity; (b) established testing system (reproduced from Figs. 2 & 3 of [1])

The strongbox (including sand specimen and the installed piles) was carefully transported and placed into the swinging basket of the centrifuge (Figure 5). Lateral loading was applied by pushing the fork towards a steel rod that crossed the piles diametrically (Figure 4b). The load velocity was 0.1 mm/s at the actuator level. The data during loading were saved into a CSV file every 0.05 or 0.02 second. More details about the experimental design, materials and methods are described in [1].

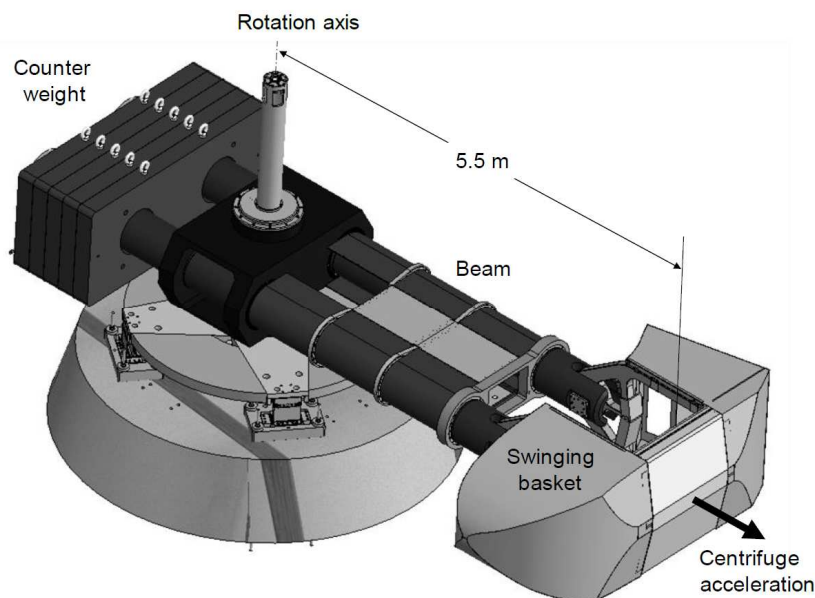


Figure 5 Schematic drawing of the beam centrifuge at University of Gustave Eiffel

### CRediT author statement

**Zhong-Sen Li:** Investigation, Writing – Original Draft

**Matthieu Blanc:** Investigation, Methodology, Software, Writing – Review & Editing

**Luc Thorel:** Validation, Supervision, Funding acquisition

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### Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### References

- [1] Z.S. Li, M. Blanc, L. Thorel, Effects of embedding depth and load eccentricity on lateral response of offshore monopiles in dense sand: a centrifuge study, *Géotechnique*. (2022) Ahead of Print, 1-15. <https://doi.org/10.1680/jgeot.21.00200>
- [2] Z.S. Li, M. Blanc, L. Thorel, Using FBGS to estimate the horizontal response of a monopile in a geotechnical centrifuge. *International Journal of Physical Modelling in Geotechnics*, 20(3) (2020), 164-174.