Data Storage Report
CentriPlug

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GEOLAB

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List of Abbreviations	
AI	Artificial Intelligence
CI	Critical Infrastructure
CA	Consortium Agreement
DOI	Digital Object Identifiers
DMP	Data Management Plan
EC	European Commission
ERA	European Research Area
FAIR	Findable, Accessible, Interoperable and Reusable
IAB	International Advisory Board
ICT	Information and Communication Technology
IP	Intellectual Property
JIP	Joint Industry Project
JRA	Joint Research Activities
MT	Management Team
NA	Networking Activities
NG	Next Generation
PGA	Participants General Assembly
PPP	Public Private partnership
RI	Research Infrastructure
SME	Small and Medium Enterprise(s)
TA	Transnational Access
TRL	Technology Readiness Level
USP	User Select Panel

1 Introduction

1.1 Scientific background

In the course of the current climate debate and enhancing the resilience of Critical Infrastructure (CI), innovative approaches for protecting coastal areas have become increasingly important, which require, besides many other topics, a better understanding of the relevant soil mechanical issues. One challenge for coastal hydraulic and geotechnical engineering in the field of soil mechanics is the use of combined steel sheet piles or open-ended steel pipe piles, which are often used as foundation elements for flood protection structures, ports, and inland waterways. The common characteristic of the mentioned piles is the open or dissolved cross-sectional area, which fills with soil during installation. A plug can form inside the pile depending on certain soil boundary conditions. Specific examples of the use of these piles are the anchoring of floating offshore structures, ship bollards, and foundation elements, such as quay walls.

The installation of open-ended piles leads to the rearrangement of soil particles, which can lead to a soil plug due to arching effects inside the pile [1]. Rearrangement and arching result in a geometrical increase of the nominal pile base, which leads to an increase in the vertical load-bearing capacity of the pile and an increase in the installation resistance. Relevant influencing factors on plug formation are the pile geometry, especially the diameter, the installation depth, and the installation method [2]. Likewise, the subsoil is an essential variable for evaluating the tendency of plug formation, where a differentiation is made between cohesive and granular soils and the subsequent potential volume reduction (contractancy) or possible volume expansion (dilatancy).

The soil plugging phenomenon is mainly investigated in detail regarding the pile installation in granular material, where a rearrangement of the grains was found to be a main result during pile installation [3],[4]. However, a significant lack of experience exists regarding open-ended pile installation and the tendency of soil plug formation in cohesive soils. The amorphousness, anisotropic structure, and water-content-related mechanics characteristic of cohesive soils show a special challenge and highlight the need for empirical investigations for both in-situ and laboratory conditions. By gaining a deeper understanding of the pile-soil interaction during the installation of open-ended piles in cohesive soils, this research project aims at exploiting the positive potentials of utilizing small-scale centrifuge models to study plug formation in cohesive soils. In conjunction with further research, including numerical and empirical investigations, the centrifuge test results will provide the basis for an analytical assessment of soil plug formation and soil plug capacity in cohesive soils, thereby promoting aspects of sustainability by minimizing anthropogenic interventions and enhancing the resilience of CI.

1.2 Aims and Objectives

CentriPlug aimed to investigate the tendency of soil plug formation in open-ended piles during their installation in soft, cohesive soils. The pile installation was modelled using small-scale centrifuge models utilizing a customized set of instrumented piles. The models allowed monitoring the internal and external radial stresses and pore water pressure development as the main values for evaluating soil plug capacity. The outcomes of CentriPlug serve as the basis for an extended program involving further modified laboratory and element testing and full-scale testing of the contact properties between pile and soil that will use instrumented open-ended piles similar to those used in this project.

2 Experimental setup

2.1 General description of experimental setup

The experiments in CentriPlug were performed in the 9.0 g-ton, 1.22-meter-radius geotechnical centrifuge at the Geo-Engineering section of the Delft University of Technology. The experimental setup consisted of three main sections: a customized open-ended pile, a 2-D, displacement-controlled driving actuator, and the soil specimen. Two pile diameters were tested as part of the testing program, namely Model 1 and Model 2. Figure 2.1 shows different views of the experimental setup mounted on the centrifuge basket.

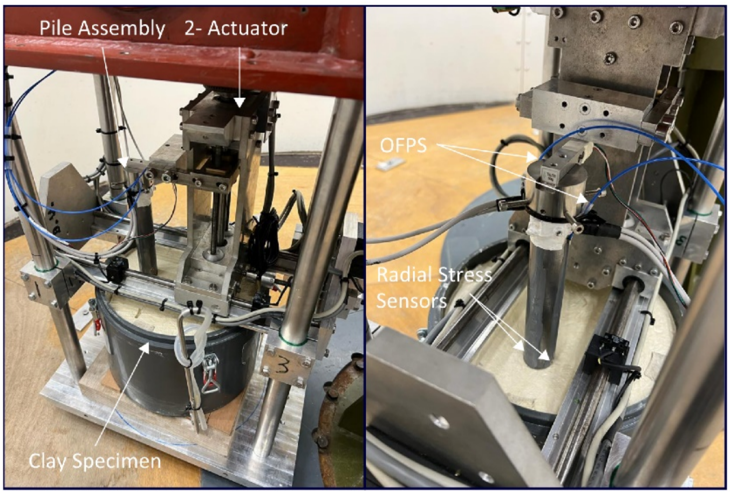

Figure 2.1: CentriPlug experimental setup for Model 1 (open-ended pile with 30 mm outside diameter)

The main section of the experimental setup is the customized set of piles designed to fit the objectives of CentriPlug. The piles were manufactured with aluminium, a wall thickness of 2 mm, and external diameters of 26 and 30 mm. Each pile includes a specific arrangement of sensors for determining the internal and external total radial stresses and the pore water pressures. The total stresses are measured using Kyowa strain gauge transducers with a measuring range of up to 500 kPa. These transducers are embedded with epoxy on the piles' wall at four locations, two inside and two outside, at distances of 6 and 18 mm from the tip. The pore water stresses are measured using FISO Optical Fibre Pressure Sensors (OFPS) with a measuring range of up to 345 kPa. These sensors are embedded in the piles through capillary tubes placed across their length during manufacturing. At the end of the capillary tubes is a metal sintering plate protecting the system against impacts and bending. A total of two OFPS are used inside and outside of each pile, at a distance of 6 mm from the pile's tip. Figure 2.2 shows a closed-up view of the piles.

The soil specimens were prepared with kaolin KDG using strongboxes with a diameter of 252 mm and a height of 285 mm. Each specimen was prepared from a kaolin-water slurry pre-consolidated under Earth's gravity to a 20 kPa vertical stress for approximately one week. Afterwards, each model sustained a consolidation stage in centrifuge by imposing a dead load of approximately 1,5 kg at a 100g acceleration for approximately eight hours. To characterize the resulting specimen, two T-bar tests were performed at different locations on each model using the T-Bar assembly available at TU Delft. Figure 2.3 shows the general dimensions of the T-Bar.

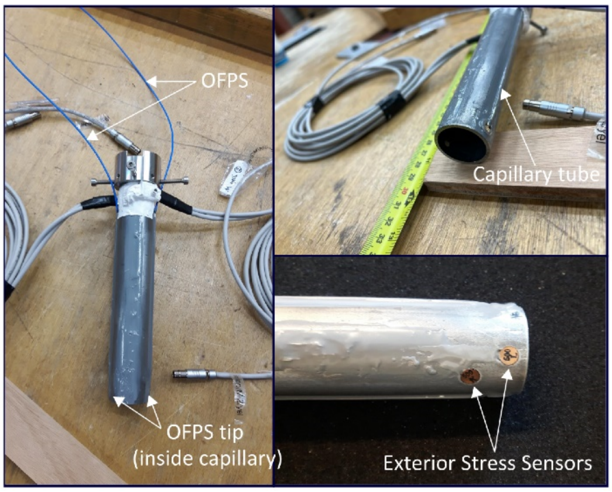

Figure 2.2: Customized pile assembly for CentriPlug

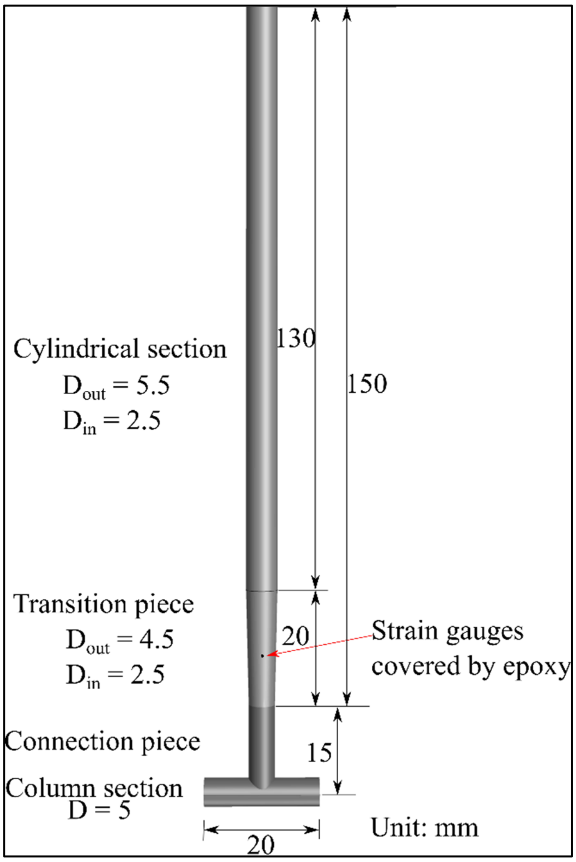

Figure 2.3: Genera dimensions of T-Bar assembly.

2.2 General data storage principles and organization of data files

CentriPlug outcomes are stored in folders composing the final repository, "GEOLAB_CENTRIPLUG." Figure 2.3 shows a general summary of the repository structure. The file “GEOLAB_CentriPlug_README.txt” contains descriptive information of the repository.

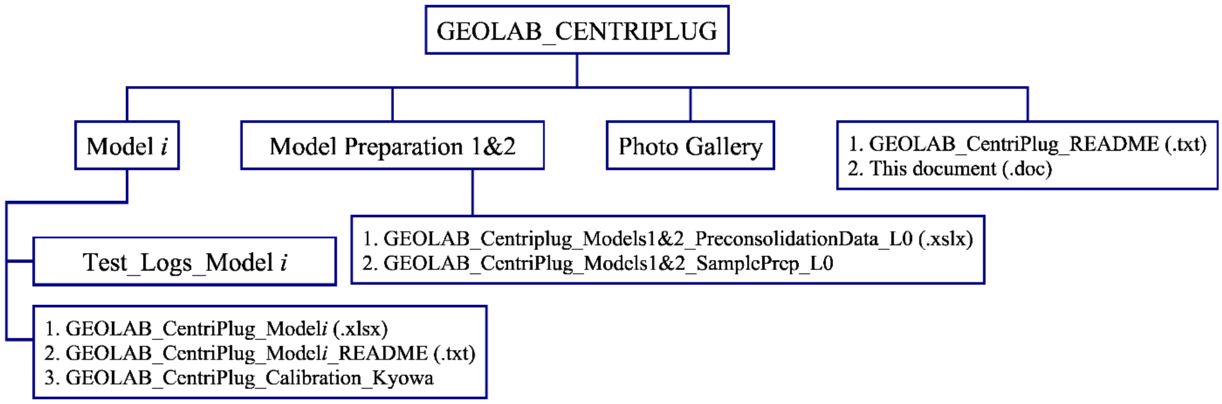

Figure 2.4: CentriPlug general data and information storage plan

The experimental data is stored in separate subfolders for every experiment, namely "Model 1" and "Model 2". Each subfolder includes an excel workbook with practical details, a descriptive text document, and an additional subfolder including the data obtained on each experiment discretized by relevant events. Information about such events is included in the excel workbook. Experimental data obtained is classified and stored based on the three-level scale described next:

1. **Level "L0"** includes raw data acquired during the experiments following the initial data acquisition conditions.
2. **Level "L1"** includes filtered data containing an specific event, such as a pile driving or T-Bar driving within the complete experimental scheme.
3. **Level "L2"** includes data subjected to any prior processing procedure.

The level category associated with any set of experimental data is defined at the end of their title.

2.3 Definition and application of spatial and temporal reference systems

For each model, two T-Bar tests and two pile-driving schemes were performed as detailed in the test program. Figure 2.4 shows the location of each test on a plan view of the surface of the specimen. Note that the origin in an x, y, z coordinate system is at the centre of the surface of each model. The tip of T-Bar or pile is initially nearly at the surface of the specimen prior to each driving sequence and then advances on the z-direction as the driving progresses.

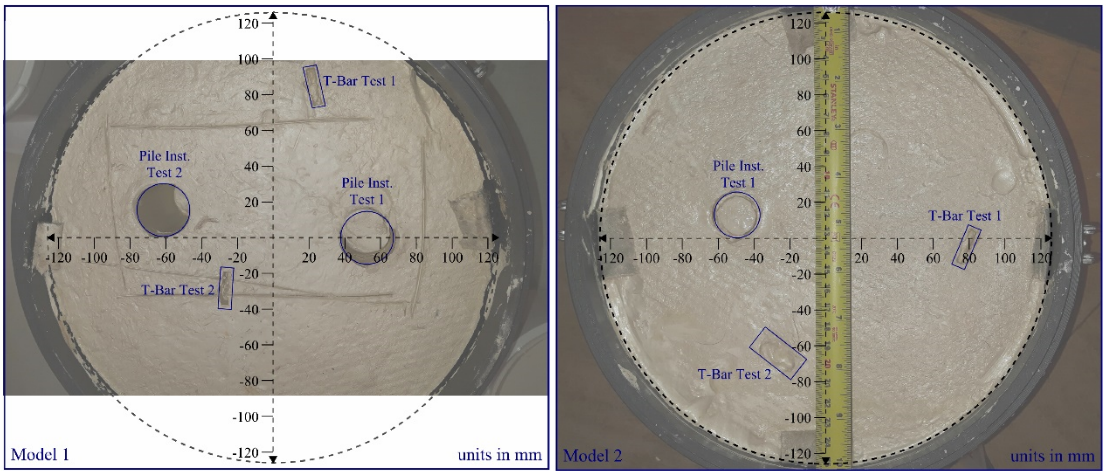

Figure 2.5: T-Bar and pile installation locations

In general, the measurements on each event or test sequence, as described in the excel workbooks, were obtained simultaneously using the acquisition system of the geotechnical centrifuge. Relevant events, such as the beginning and end of a driving sequence, were identified from the sensors' response and the actuator's maximum displacement.

2.4 Relevant fixed parameters

There are not relevant fixed parameters on the experiments different than those mentioned on other sections within this document.

2.5 Test Programme

As indicated previously, CentriPlug consisted of two setups with two different pile diameters, namely Model 1 and Model 2. The test programme for each model comprised four main stages, including Model Preparation, TBar Testing, Pile Installation Modelling, and Post-test Characterization. Details of the program can be encountered in the excel workbooks.

The initial stages of Model Preparation and TBar Testing consisted of the specimen preparation and specimen strength evaluation as described in section 2.1. During the Pile Installation Modelling stage, the setup was initially spun up to the target gravitational acceleration field. Afterwards, the pile installation was performed by driving the pile into the specimen at a controlled displacement rate until the maximum displacement possible by the actuator was achieved. A period of time defined during the experiments was allowed to monitor the response of the model before pulling out the pile. The pull-out sequence was performed at the target g-level or at 1g depending on the model. After the driving sequence, the centrifuge was spun down and the model was set to a second installation model repeating the same sequence. Moisture content measurements were obtained at various locations within the model at the end of the testing program.

3 Instrumentation – Model 1

3.1 Instruments

A summary of the instruments utilized in Model 1 is shown in Table 3.1. Further information, including calibration constants are indicated on the excel workbook for Model 1. With the exception of OFPS, for which a specialized signal conditioner was used, the output from all sensors were conditioned utilizing the built-in system of the geotechnical centrifuge. All data acquisition was performed through the same built-in system.

During the consolidation sequence, the single point, laser displacement sensor was fixed to the upper portion of the swinging basket, and it was aimed to a target located on the surface of the model. The initial reading was zeroed before spinning-up.

Table 3.1: Summary of instrumentation on Model 1

Instrument	Sensor/Transducer	Model	Serial Number
T-Bar Assembly	Donut Load Cell	N/A	N/A
	Strain Gages (2 units)	N/A	N/A
Pile Assembly	Miniature Pressure Sensor (4 units)	Kiowa PS-5KC (0-500 kPa)	N/A
	Optical Fiber Pressure Sensors (2 units)	FISO FOP-M-NP in SS304 (0-350 kPa)	N/A
	OFPS Signal Conditioner (2 units)	FISO FPI HS	N/A
	Beam Load Cell	HT TAL220 50kg	N/A
Others	Single point, laser displacement sensor	Althen FDRF602-65/250	32064

3.2 Measured parameters

Table 3.2 shows the parameters measured and the initial conditions prior to recording.

Table 3.2: Initial conditions and general output of instruments on Model 1

Instrument	Sensor/Transducer	Measurement	Initial Condition
T-Bar Assembly	Donut Load Cell	Force (N)	Unloaded (tared)
	Strain Gages (2 units)	Force (N)	Unloaded (tared)
Pile Assembly	Miniature Pressure Sensor (4 units)	Output Voltage (V)	Unloaded (offset)
	Optical Fiber Pressure Sensors (2 units)	Absolute Pressure (kPa)	Environment Pressure
	Beam Load Cell	Force (kg)	Unloaded (offset)
Others	Single point, laser displacement sensor	Displacement (mm)	Surface of Model (tared)

3.3 Experimental procedure

Table 3.3 shows a summary of the calibration details and the initial configuration used during calibration and test. Sensors on the pile assembly were calibrated inside a pressure chamber under various increment of pressure (see “GEOLAB_CentriPlug_Calibration_Kyowa” for calibration data).

Table 3.3: General configuration and calibration process for instruments on Model 1

Instrument	Sensor/Transducer	Configuration	Calibration Process
T-Bar Assembly	Donut Load Cell	Full bridge, Input 2.5V, 500x Amplification	Pre-calibrated
	Strain Gages (2 units)	Full bridge, Input 2.5V, 500x Amplification	Pre-calibrated
Pile Assembly	Miniature Pressure Sensor (4 units)	Full bridge, Input 2.5V, 10x Amplification	Pressure Chamber
	Optical Fiber Pressure Sensors (2 units)	OFPS Signal Conditioner	Pressure Chamber
	Beam Load Cell	Full bridge, Input 2.5V, 10x Amplification	Controlled Dead Weight
Others	Single point, laser displacement sensor	Full bridge, Input 2.5V, 100x Amplification	Calibrated Target Displacement (pre-calibrated)

3.4 Data post-processing

No data processing was carried out by the time of this report (i.e., Level “L2” data).

3.5 Organization of data files

See section 2.2 for information regarding data files.

3.6 Remarks

All relevant details are presented throughout this document.

4 Instrumentation – Model 2

4.1 Instruments

A summary of the instruments utilized in Model 2 is shown in Table 4.1. Further information, including calibration constants are indicated on the excel workbook for Model 2. With the exception of OFPS, for which a specialized signal conditioner was used, the output from all sensors were conditioned utilizing the built-in system of the geotechnical centrifuge. All data acquisition was performed through the same built-in system.

During the consolidation sequence, the displacement sensor was fixed to the upper portion of the swinging basket, and it was tied to a target located on the surface of the model. The initial reading was zeroed before spinning-up.

Table 4.1: Summary of instrumentation on Model 2

Instrument	Sensor/Transducer	Model	Serial Number
T-Bar Assembly	Donut Load Cell	N/A	N/A
	Strain Gages (2 units)	N/A	N/A
Pile Assembly	Miniature Pressure Sensor (4 units)	Kiowa PS-5KC (0-500 kPa)	N/A
	Optical Fiber Pressure Sensors (2 units)	FISO FOP-M-NP in SS304 (0-350 kPa)	N/A
	OFPS Signal Conditioner (2 units)	FISO FPI HS	N/A
	Beam Load Cell	HT TAL220 50kg	N/A
Others	Displacement sensor	Micro-Epsilon WPS-150-MK30-P25	9862

4.2 Measured parameters

Table 4.2 shows the parameters measured and the initial conditions prior to recording.

Table 4.2: Initial conditions and general output of instruments on Model 2

Instrument	Sensor/Transducer	Measurement	Initial Condition
T-Bar Assembly	Donut Load Cell	Force (N)	Unloaded (tared)
	Strain Gages (2 units)	Force (N)	Unloaded (tared)
Pile Assembly	Miniature Pressure Sensor (4 units)	Output Voltage (V)	Unloaded (offset)
	Optical Fiber Pressure Sensors (2 units)	Absolute Pressure (kPa)	Environment Pressure
	Beam Load Cell	Force (kg)	Unloaded (offset)
Others	Displacement sensor	Displacement (mm)	Surface of Model (tared)

4.3 Experimental procedure

Table 4.3 shows a summary of the calibration details and the initial configuration used during calibration and test. Sensors on the pile assembly were calibrated inside a pressure chamber under various increment of pressure (see "GEOLAB_CentriPlug_Calibration_Kyowa" for calibration data).

Table 4.3: General configuration and calibration process for instruments on Model 2

Instrument	Sensor/Transducer	Configuration	Calibration Process
T-Bar Assembly	Donut Load Cell	Full bridge, Input 2.5V, 500x Amplification	Pre-calibrated
	Strain Gages (2 units)	Full bridge, Input 2.5V, 500x Amplification	Pre-calibrated
Pile Assembly	Miniature Pressure Sensor (4 units)	Full bridge, Input 2.5V, 10x Amplification	Pressure Chamber
	Optical Fiber Pressure Sensors (2 units)	OFPS Signal Conditioner	Pressure Chamber
	Beam Load Cell	Full bridge, Input 2.5V, 10x Amplification	Controlled Dead Weight
Others	Displacement sensor	Full bridge, Input 2.5V, 100x Amplification	Calibrated Target Displacement (pre-calibrated)

4.4 Data post-processing

No data processing was carried out by the time of this report (i.e., Level “L2” data).

4.5 Organization of data files

See section 2.2 for information regarding data files.

4.6 Remarks

All relevant details are presented throughout this document.

5 References

[1] Klos, J.; Tejchmann, A. (1981): Bearing capacity calculation for pipe piles. In: *Proc. of the 10th Intern. Conf. on Soil Mech. and Foundation Eng.*, Stockholm, Sweden.
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[3] Henke, S. (2020): Soil plug investigation with respect to pile geometry and installation method. In: *ECPMG 2020 – 4th European Conf. on Physical Modelling in Geot.*, Eds.: Jan Laue & Tarun Bansal, pp. 125–132.
[4] Henke, S.; Grabe, J. (2012): Field measurements regarding the influence of the installation method on soil-plugging in tubular piles. In: *Acta Geotechnica* (8), pp. 335–352.

Appendices

No appendices were prepared as part of this version of the report.


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