Data from ice tank tests with vertically sided structures collected during the SHIVER project

Authors

Hayo Hendrikse[1], Tim C. Hammer[1], Marnix van den Berg[1], Tom Willems[2], Cody C. Owen[1], Kees van Beek[1], Nick J. J. Ebben[1], Otto Puolakka[3], Arttu Polojärvi[3]

Affiliations

[1]Delft University of Technology, Department of Hydraulic Engineering, Delft, The Netherlands
[2]Formerly: Siemens Gamesa Renewable Energy, The Hague, The Netherlands
[3]Aalto University, Espoo, Finland

Corresponding author

Hayo Hendrikse

Contact information

h.hendrikse@tudelft.nl

TU Delft – Faculty of Civil Engineering and Geosciences
Stevinweg 1
2628 CN Delft
The Netherlands

General introduction

Basin tests were performed at the Aalto Ice Tank to gather data on ice-structure action and interaction in May and June, 2021. The Aalto Ice Tank is an indoor testing facility that is part of the Department of Mechanical Engineering at Aalto University. A real-time hybrid test setup was mounted to a carriage on a bridge spanning the ice tank (see Hammer et al. (2019) for more details). A vertically sided cylindrical pile was moved through the ice by moving the carriage along the bridge. The dynamic response to the measured ice loads was simulated by the real-time hybrid test setup for a range of test structures including offshore wind turbines, a series of single- and multi-degree-of-freedom oscillators, the Norströmsgrund lighthouse and the Molikpaq caisson structure. In addition, ice loads were measured in forced vibration tests and while moving the rigid pile through the ice with a constant speed.

A detailed description of the data and experimental design has been submitted to Data in Brief. The manuscript is titled: “Experimental data from ice basin tests with vertically sided cylindrical structures”.

The data was collected as part of the SHIVER project – An advanced ice model for application in design of offshore wind turbines susceptible to ice-induced vibrations based on model-scale experiments. The project partners are TU Delft, Siemens Gamesa Renewable Energy, and Aalto University. The project is funded by TKI-Energie uit de Toeslag voor Topconsortia voor Kennis en Innovatie van het ministerie van Economische Zaken en Klimaat (TKITOE_WOZ_1906_TUD_SHIVER).

Data description

The primary dataset consists of 259 test files, stored in the CSV format. Each test file contains data on the measured ice loads, carriage movement and structure dynamics. In addition to the test files, there are video recordings of each test from three different viewpoints and there are data on the ice material properties and the ice thickness.

The tests were performed with a real-time hybrid test setup. The setup combined physical and numerical components to simulate structures in real-time. A numerical model of a test structure responded to the measured ice loads. The numerically calculated waterline displacements were applied to a physical cylindrical pile which was interacting with the ice. The 2D pile motion in the horizontal plane was driven by bi-directional linear actuators. The test setup was mounted to a carriage running under a bridge that spans the ice tank.

The basin tests were performed in nine ice sheets over a period of four weeks. Data from eight ice sheets have been uploaded, as the first ice sheet was considered a trial sheet and did not meet the ice quality requirements. Figure 1 gives an overview of the test data and numbering conventions in relation to an ice sheet. It also shows the positioning conventions and the test direction used in all tests.

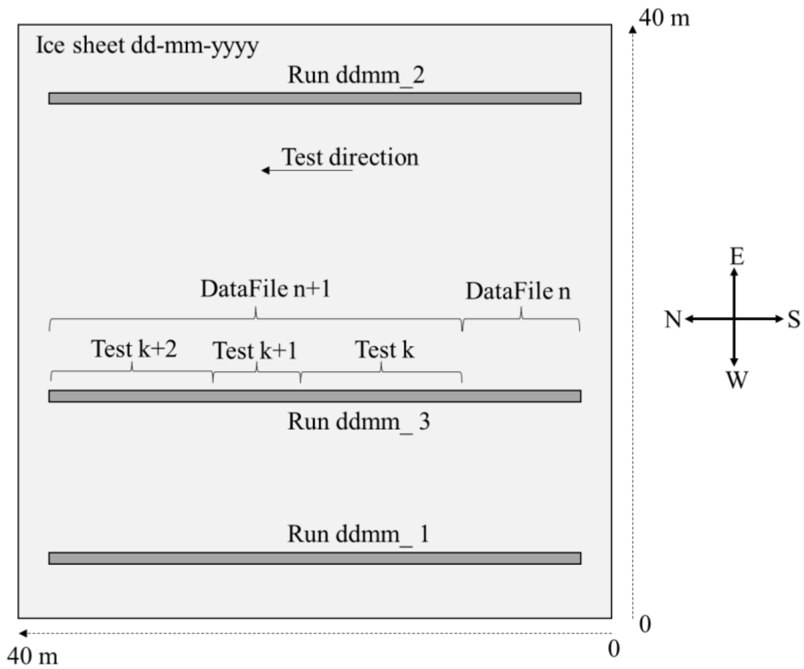

Figure 1. Top-view sketch of an ice sheet, showing dimensions, position conventions, test direction and numbering system for sheets, runs, data files and tests.

In each ice sheet, between one and 12 runs were made. A run is a single passing of the carriage from the South side of the ice basin to the North side of the basin. During a single run, one or several data recordings were made. The continuous data recordings are stored in *data files.* Each data file may contain several tests with different test conditions. The data recorded for each test is stored in *test files.* Test files are subsections of data files and contain continuous time series measurements under constant or linearly varying (in the case of carriage speed) test conditions.

The ice sheets are identified by their creation date. The runs are numbered based on the run order in each individual ice sheet. The data files are numbered consecutively based on the order of recording. The tests are classified by a unique numeric identifier, numbered consecutively based on the ingestion date of the test data into a database.

Data file format

Database

The database file provides a tabulated overview of the test data. The database file consists of seven tabs. The data content of each tab is described in Table 1.

Table 1. Tabs and data in the database file.

FrontPage
The FrontPage tab contains the database template revision date. It also gives an overview of the subdivision of iceSheets, runs, dataFiles and tests.
IceSheets
The IceSheets tab gives an overview of the ice sheets. It summarizes the measured material properties of each sheet.
Runs
The Runs tab gives an overview of the runs. It lists the ice thickness measurements performed in each run.
Tests_overview
The Tests_overview tab links the tests to the runs and to the dataFiles. In addition, it lists the test type, the test subtype and the ice speed.
Tests_struc
The Tests_struc tab contains the data that is specific to tests where the real-time-hybrid test setup models a structure. It lists the structure template file used in the tests, the actuator offset, the ice-wind misalignment angle and the wind load file name.
Tests_forced
The Test_forced tab contains the data that are specific to the forced vibration tests. It contains the vibration frequency and amplitude in x- and y-directions, and the phase difference between x and y vibrations for the tests where both were applied at the same time.
Tests_start_end
The Tests_start_end tab contains the start and end times of the tests within the data files, and the file names of the test files created by partitioning the data files.

CVSTestFiles and CSVDataFiles

All test data are stored in CSV files. Table 2 gives an overview of the data columns in the data and test files. The data columns FinX_N, FinY_N, ExtFx_N, ExtFy_N, ExtDx_mm, ExtDy_mm and DampCoeff are sampled at a lower frequency than the other fields and are not guaranteed to be time synchronized with the other data. The main purpose of these fields is to verify whether the measured ice loads and the numerically applied external forces and displacements were correctly received by the control system. The other fields are time-synchronized and are recorded for most tests with a frequency of 2000 Hz. Only the data file *Mode_306*, and tests with IDs 85-96, which are subsections of that data file, are sampled at 10000 Hz.

The file names of the test data files are structured as follows:
Test<ID>_<day><month>_<run number>_<test type>_v<ice speed>_<creation date and time>

It is noted that the y-direction is in general the direction of the ice drift (simulated by carriage motion during the tests). A sketch of the setup indicating the different levels where sensors have been placed is included in Figure 2. The potentiometers were installed at the bottom of the pile. Displacements of the pile were measured using magneto strictive displacement sensors. Load cells were connected to the end of the actuators. It is recommended to watch some of the videos to get a better idea of the setup.

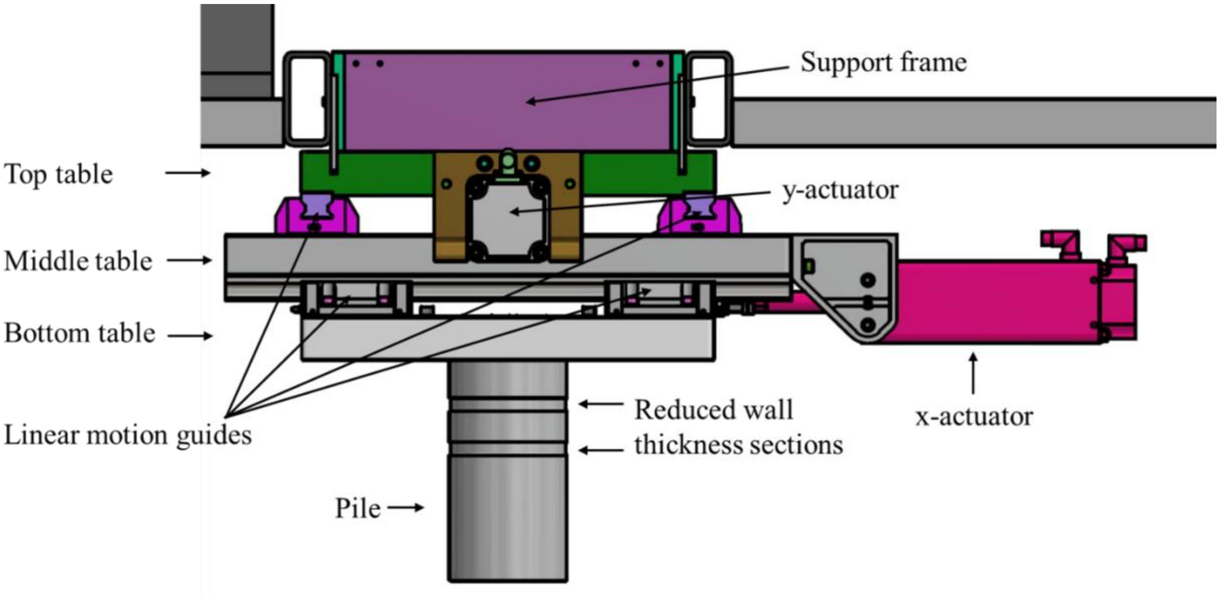

Figure 2. Side-view sketch of the real-time hybrid test setup.

Table 2. Data columns in test data files.

Column name	**Unit**	**Explanation**
Date	days	Date and time of day, in days since 1900, Central European Summer Time (CEST)
Time_s	s	Time from start of recording
FinX_N	N	Total input force as applied to the structural model, x-direction (verification only!)
FinY_N	N	Total input force as applied to the structural model, y-direction (verification only!)
ExtFx_N**	N	External numerically applied load in x-direction (verification only!)
ExtFy_N**	N	External numerically applied load in y-direction (verification only!)
ExtDx_mm**	mm	Numerically applied displacement in x-direction (verification only!)
ExtDy_mm**	mm	Numerically applied displacement in y-direction (verification only!)
DampCoeff**	-	Coefficient indicating the ratio between DampStrt and DampEnd values
FLoadX_N	N	Load cell force in x-direction
FLoadY_N	N	Load cell force in y-direction
FPileX1_N	N	Ice force in x-direction, derived from upper ring of strain gauges
FPileY1_N	N	Ice force in y-direction, derived from upper ring of strain gauges
Pm1X	N	Potentiometer signal, x-direction
Pm1Y	N	Potentiometer signal, y-direction
Acc1Y_ m_s2	$m\ s^{-2}$	Pile accelerometer, x-direction
Acc1X_ m_s2	$m\ s^{-2}$	Pile accelerometer, y-direction
Acc1Z_ m_s2	$m\ s^{-2}$	Pile accelerometer, z-direction
Acc2X_ m_s2	$m\ s^{-2}$	Lower table accelerometer, x-direction
Acc2Y_ m_s2	$m\ s^{-2}$	Lower table accelerometer, y-direction

Acc2Z_ m_s2	$m\ s^{-2}$	Lower table accelerometer, z-direction
Acc3X_ m_s2	$m\ s^{-2}$	Middle table accelerometer in x-direction
Acc3Y_ m_s2	$m\ s^{-2}$	Middle table accelerometer, y-direction
Acc3Z_ m_s2	$m\ s^{-2}$	Middle table accelerometer, z-direction
Acc4X_ m_s2	$m\ s^{-2}$	Top table accelerometer in x-direction
Acc4Y_ m_s2	$m\ s^{-2}$	Top table accelerometer, y-direction
Acc4Z_m_s2	$m\ s^{-2}$	Top table accelerometer, z-direction
SOutX2_mm	mm	Target displacement of the x-actuator
SOutY2_mm	mm	Target displacement of the y-actuator
DisplX_mm	mm	Measured table displacement in x-direction
DisplY_mm	mm	Measured table displacement in y-direction
LED*	-	For synchronization of videos and data.
SOutXnoFP_mm**	mm	Numerical waterline displacement without forward prediction, x-direction
SOutYnoFP_mm**	mm	Numerical waterline displacement without forward prediction, y-direction
CarVel_mm_s	$m\ s^{-1}$	Carriage speed
CarPos_m	m	Carriage position

*: *Data column present in tests with IDs ≥ 145*

**: *Data column present in tests with IDs ≥ 363*

Video files

Video recordings were made for each test from three different view-points: x-view, y-view, and table-view. The video recordings are divided into one file per viewpoint per test run. The video file names are structured as follows:

<year>_<month>_<day>_<camera position>_R<run number>

The camera position can be XV (x-view), YV (y-view) or TV (table-view).

Structural files

The structural files define the dynamic properties of the structures simulated by the real-time hybrid test setup. The meaning of the data columns in the structure files is clarified in Table 3.

Table 3. Structure file columns

Name	Meaning	unit
ModeNr	Number of the mode (zero-based indexing)	[-]
Enable	Flag specifying if the mode should be enabled in the numerical model	[-]
Freq	Modal frequency	[Hz]
DampStrt	Start value of modal damping, defined as the logarithmic decrement.	[-]
DampEnd	End value of modal damping, defined as the logarithmic decrement.	[-]
Ampl_msl_X and Amp_msl_Y	Mass-normalized modal amplitude at the ice action point in x- and y-directions	$[kg^{-\frac{1}{2}}]$
Ampl_tt_X and Ampl_tt_Y	Mass-normalized modal amplitude at the tower top in x- and y-directions (only used in the application of wind loading)	$[kg^{-\frac{1}{2}}]$

For the offshore wind turbine tests with wind-ice misalignment, the structure coordinate system in which the mode shape amplitudes are defined is rotated by angle φ to the coordinate system of the physical pile. The measured data are always defined in the coordinate system of the physical test pile.

Wind load files

The wind load files define the time-domain wind load fluctuations at the rotor-nacelle-assembly of the numerically implemented structures. Wind load files contain the following data columns (Table 4):

Table 4. Column names wind load file.

Time [s]	
ValX [N]	Wind load variation in x-direction
ValY [N]	Wind load variation in y-direction

Example plot files

These are MATLAB scripts showing how the test data can be filtered and visualised.

References

T.C. Hammer, K. van Beek, J. Koning, H. Hendrikse, A 2D test setup for scaled real-time hybrid tests of dynamic ice- structure interaction, in: Proc. 26th Int. Conf. Port Ocean Eng. under Arct. Cond., Moscow, Russia, 2021.