DURCWAVE

Data Storage Report

DURCWAVE – CIEM

Project Information

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Social Media	@durcwave_msca
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Project Personnel

Role	Name	Institution	Email	ORCID-id
Project Supervisor	Xavier Gironella I Cobos	UPC	xavi.gironella@upc.edu	0000-0002-8862-5704
Main Researcher	Corrado Altomare	UPC	corrado.altomare@upc.edu	0000-0001-8817-0431
Technical Staff	Joaquim Sospedra Iglesias	UPC	Joaquim.sospedra@upc.edu	0000-0003-4207-7922
Erasmus student	Mauro Campagnola	Politecnico di Bari	m.campagnola@studenti.poliba.it	-
Erasmus student	Maria Luigia Robustelli	Università di Salerno	marialuigiarobustelli@gmail.com	-

Document objective

This data storage report describes the project and how data were collected. The data are described so that others can use them.

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1 Introduction

1.1 Background

In early 2020, the so-called sea storm Gloria hit the Mediterranean coasts of Spain and France: the combination of long-lasting extreme wave conditions and wind velocities caused severe damages to assets and infrastructures. The Pont del Petroli, a pier located in Badalona, in the northern area of Barcelona, Spain, was heavily damaged. Pont del Petroli is a coastal structure integrated into the coastline with high historical, scientific and social value. The pier head platform suffered from serious damages, most likely due to the induced shear stress in the concrete and exceeded soil bearing capacity. Besides, one of the concrete beams that form the footbridge (the first one connected to the platform) was completely washed away.

1.2 Objectives

The aim of the experimental campaign was to characterize the forces involved in the failure of the Pont del Petroli (Badalona, Catalonia) due to the storm Gloria happened in the night of the 20 January 2020. The experiments were carried out in the CIEM (Canal d'Investigacio' I Experimentacio' Maritima) wave flume in the laboratory of maritime engineering of the UPC (Universitat Politecnica de Catalunya - BarcelonaTech, Barcelona, Catalonia).

In preparation for the experimental campaign, numerical simulations have been chosen as a means to obtain accurate predictions of water flow around the pier under certain extreme weather conditions (Altomare et al., 2020).

2 Experimental setup

2.1 Facility

Experiments were conducted in the Canal d'Investigació i Experimentació Marítima (CIEM), see Fig. 2.1, wave flume at the Universitat Politècnica de Catalunya, (UPC), Barcelona. This large research facility is 100 m long, 3 m wide and 4.5 m deep. Typical working scales are between 1/2 to 1/20. Waves and currents are generated by a wedge-type wave generator, the system is hydraulically actuated and PC-controlled. This is also capable to produce waves with heights up to 1.6 m. The control software allows regular and irregular waves generation.

Figure 2-1: CIEM wave flume

2.2 Definition of the coordinate system

The origin of the reference system used is placed in the middle of the stroke of the wave paddle and lies on the rigid bottom of the wave flume

- X follows the direction along the flume and is positive when going towards the shoreline. The absolute 0 is at the wave paddle.
- Y refers to the cross-shore distance of the flume. Just a few notations have been done using this reference and the 0 is at the wall in which the Wave gauges were placed.
- The original Z coordinate is directed vertically with the 0 located at the concrete bottom of the flume at the toe of the wave paddle.

2.3 Model setup

The geometrical scale of the model is 1/10. Figure 2-2 and Figure 2-3 show the scaled model of the Pont del Petrolí. The model is realized in steel, except for the plates forming the cover of the platform and footbridge, made in plywood. The platform starts at $x=54$ m. The foreshore, starting approx. at $x=32$ m is made of sand. The sediment consisting of medium sand $d_{50}=0.25$ mm, with a narrow grain size distribution ($d_{10}=0.154$ mm and $d_{90}=0.372$ mm) and a measured settling velocity (w_s) of 0.034 m/s. The sand used for this experiment is provided by Sibelco being the commercial name J5060S.

Figure 2-2: Representation of the scaled model of Pont del Petroli (only the platform and the first two footbridge beams have been built)

Figure 2-3: Sketch of the model of Pont del Petroli and beach profile

Geometrical details of the structural model as built have been sketched in Autocad and are reported in the *PontdePetroli_escala_1_10_real.dwg*.

3 Instruments

The characteristics of instruments used are described in the following.

1. Resistance Wave Gauges (WG)
2. Acoustic Wave Gauges (AWG)
3. Pore Pressure Sensors employed for surface elevation measurements (PPT)
4. Load cells (LC)
5. Pressure Sensors employed for measurements of exerted pressure on the footbridge (PS)
6. Echo Sounder

For water surface elevation were employed: 9 acoustic sensors AWG (Acoustic Wave Gauge), 10 resistive sensors RWG (Resistive Wave Gauge), 10 pore pressure transducers PPT (see Figure 3-1). Location of the sensors and corresponding channel (=column) in the output file of data acquisition are reported in Table 3-1. For the PPTs, the Z-coordinate of their placement and the corresponding local water depth values are reported in Table 3-2.

The sensor used for the measurement of forces on the platform of the pier are: 4 load cells for the measurement of vertical forces on the corners of the platform (LC1-LC4), 2 load cells for the measurement of horizontal forces on the front of the platform (LC5, LC6), 1 load cell for the measurement of horizontal forces on the first pile cap (LC7), 3 pressure sensors on the deck of the pier (PS1, PS7, PS8). A sketch representing the LCs and PSs placement is depicted in Figure 3-2). Sampling frequency of AWGs, WGs and PPTs is 40 Hz, meanwhile 2400 Hz is used for LCs and PSs.

Table 3-1: Label and location of water surface elevation sensors

Label	Channel in the acquisition output file	X (m)
WG0	3	11.86
WG13	4	11.86
AWG6	19	17.64
AWG0	13	19.44
AWG9	21	21.6
AWG5	18	23.6
AWG1	14	25.6
WG2	5	27.02
AWG2	15	27.6
WG3	6	28.57
AWG3	16	30.3
PPT0	22	34.41
WG7	7	35.96
PPT1	23	37.81
PPT2	24	41.96
WG11	8	44.13
PPT3	25	46.14
WG5	9	48.16
AWG4	17	50.24
WG6	10	52.12
WG8	11	53.55

AWG7	20	54
WG9	12	55.11
PPT5	26	57.83
PPT6	27	59.14
PPT8	29	60.41
PPT9	30	62.51
PPT11	31	64.73
PPT12	32	65.46
PPT13	33	67.11

On 05/02/2021, from test 050221_37 on, the AWG7 has been moved to measure overtopping flows on the platform. The next position is: $x=54.46\text{m}$, distance from the flume right wall= 1.49 m , distance from the platform $z=0.61\text{ m}$.

Figure 3-1: Position of sensors along the CIEM (red circles = AWG, blue squares = PPT, black triangle = WG).

Table 3-2: Z-coordinate of the pressure transducers and local water depth values

Label	Z (m)	Local depth (m)*
PPT0	1.24	2.44
PPT1	1.41	2.20
PPT2	1.4	1.89
PPT3	1.37	1.60
PPT5	2.05	0.77
PPT6	2.04	0.72
PPT8	2.04	0.71
PPT9	2.04	0.64
PPT11	2.22	0.55
PPT12	2.21	0.53
PPT13	2.19	0.48

*It can vary slightly from test to test due because of small changes in the beach profile.

Figure 3-2: 3D drawing of the Pont del Petroli model as built in the flume. (red = supporting piles; white = horizontal elements; green = LCs and PSs).

3.1 Instruments characteristics

3.1.1 RESISTANCE WAVE GAUGES

Description

The resistance type wave gauges used in the CIEM operate on the principle of measuring the current flowing in an immersed probe which consists of a pair of parallel stainless-steel wires (the absence of other support reduces the interaction between the measuring device and the incoming/reflected waves). The current flowing between the probe wires is proportional to the depth of immersion and this current is converted into an output voltage proportional to the instantaneous depth of immersion. The output circuitry is suitable for driving both a chart recorder and a data logger.

Each wave probe needs a wave probe monitor with the energising and sensing circuits for the operation. Each monitor contains the circuits required to compensate for the resistance of the cable that is connected to the probe. Without this, the output of the wave probe monitor would be non-linear. In order to avoid polarization effects at the probe surface, a high frequency square wave voltage is used to energise the probe. The oscillator that produces this square wave may be set to one of six different frequencies. This allows probes to be used close together without causing any interference.

The current in each probe is detected by measuring the voltage drop across two resistors. Because the measured voltage is alternating, the signal is fed to a precision rectifier to produce a DC voltage proportional to the wave height. This signal feeds a small centre-zero balance indicator and a BNC socket on the front of the panel. The signal is also fed to a pre-set gain stage that may be set for a gain of between 0.5 and 10. Controls on the front of each wave probe module enable the output signal to be set to zero for any given initial depth of probe immersion. This, together with the gain adjustment, produces a full-scale output of $\pm 10V$ for all waves.

Application range

The steel wires lengths allow detect any wave height up to 2m.

Calibration

The transformation function (from voltage to depth) is calibrated due the possible changes in the water conductivity (temperature and salinity concentration effects). An overall calibration from wave height to output voltage can be performed by measuring the change in output voltage, raising or lowering the mean water level of the flume.

Data acquisitions

The laboratory works with a global data acquisition system. The data acquisition component supports the following hardware manufacturers:

Data Translations boards which is supported by the Open-Layer interface.

National Instruments boards supported by NI-DAQmx 8.6

The component supports data acquisition on several boards at the same time as long as they are from the same manufacturer. The component supports controlling of external equipment through digital and analogical outputs which can be triggered on a specified time or by an input channel. Component supports high throughput using hardware trigger which leads to little cpu utilization for even high sampling frequencies (>1 kHz).

Specifications

Output Signals:	front of monitors $\pm 10V$ via BNC socket
	rear of case $\pm 10V$ via 25 way D socket
Gain	0.5, 0.75, 1.0, 1.5, 2.55, 3.75, 6.0, 10.0
Excitation frequency	4.6 kHz to 11.6 kHz
Filter band width	-3dB at 20Hz
Supply voltage	220 or 110V $\pm 10\%$ 40-60Hz
Active length	2000 mm
Diameter	1.5 mm

3.1.2 ACOUSTIC WAVE GAUGES

Two different kind of AWG have been used on the performed experiments large range and medium range. Here both are presented.

Long Range

Description

The ULS-40D is an Acoustic sensor that emit ultrasound pulses that reflect on the measurement object and is received back as an echo.

Application range

From 0.18 m up to 3.5 m

Calibration

Calibration is need for every device to correlate the output voltage signal to distances.

Data acquisitions

The ultrasound measurement system outputs a voltage proportional to distance of between 0 and 10 V. A calibration straight line, previously done, is applied to the output voltage to transform the intensity signal to the proportional distance.

Specifications

Accuracy	Up to +/- 1 mm (under stable environmental conditions)
Resolution	from 0.18 m to 3.5 m
Measurement frequency	from 20 to 75 Hz
Voltage output	BNC socket: 0 – 10V
Beam angle	<3°
Power supply	230 VAC, 250 mA
Temperature range	-20 / +70 °C

Medium Range

Description

The mic+130 from Microsonic is an Acoustic sensor that emit ultrasound pulses that reflect on the measurement object and is received back as an echo.

Application range

From 0.20 m up to 1.7 m

Calibration

Calibration is need for every device to correlate the output voltage signal to distances.

Data acquisitions

The ultrasound measurement system outputs a voltage proportional to distance of between 0 and 10 V. A calibration straight line, previously done, is applied to the output voltage to transform the intensity signal to the proportional distance.

Specifications

Resolution, sampling rate	up to 0.18 mm
Resolution	from 0.2 m to 1.7 m
Transducer frequency	200 kHz
Voltage output	BNC socket: 0 – 10V
Power supply	230 VAC, 250 mA
Temperature range	-25 / +70 °C

3.1.3 PORE PRESSURE SENSORS (PPT)

Description

Provided by STS the ATM/N pressure sensors have the next characteristics

Application range

Up to 100 or 400 mb (1 and 4 m of water respectively)

Calibration

They are calibrated by using a calibration pipe.

Data acquisitions

The signal intensity output is related, taking into account the calibration curve of each probe, to water height.

Specifications

Accuracy				< 0.5
Thermal shift	Zero	0.....70°C		0.06 -25...85°C
0.08				
		Span	0.....70°C	
0.015				-25...85°C
0.02				

3.1.4 LOAD CELLS (LC)

The load cells employed to measure the forces exerted by the waves on the pier elements comprise four S-type load cells (TEDEA Model 616) and three beam type load cells (model Z6FC3).

S-type load cells

Description

TEDEA, Model 616 compression-tension load cells

Application range

Up to 300 Kg

Calibration

They are calibrated with the software CatManEasy v3.4.2 by applying different weights. Eigen-frequency of the load cells is characterized by hammer-test once they are mounted on the structure.

Data acquisitions

A calibration function is applied to the output voltage to transform the intensity signal to the proportional weight. Sampling frequency is 2400 Hz.

Specifications

Accuracy	≈ 0.03%*rated capacity
Temperature range	-10 to +45 °C
Weight	0.58 kg
Construction	Stainless Steel

Beam-type load cells

Description

Model Z6FC3.

Application range

50-500 Kg

Calibration

They are calibrated with the software CatManEasy v3.4.2 by applying different weights. Eigen-frequency of the load cells is characterized by hammer-test once they are mounted on the structure.

Data acquisitions

A calibration function is applied to the output voltage to transform the intensity signal to the proportional weight. Sampling frequency is 2400 Hz.

Specifications

Accuracy	$\approx 0.05\%$ *rated capacity
Temperature range	-10 to +40 °C
Weight	0.50 kg
Construction	Stainless Steel

3.1.5 PRESSURE SENSORS (PS)

Description

Model P8AP, 2 mV/V strain gage sensor. Working for static and dynamic pressure.

Application range

10-500 bar

Data acquisitions

Sampling frequency is 2400 Hz.

Specifications

Nominal rate sensitivity	2±2% mV/V
Control volume	0.3-2 mm ³
Temperature effect on the zero signal relative to the actual value per 10 K	±0.3
Weight	250 g

3.1.6 Echo Sounder

Description

UltraLab UWS echo sounder is used for highly spatial and temporal resolved measurements of distances in fluids. It works with an ultrasonic impulse runtime procedure and the 1MHz, highly sensitive transducer with a very narrow beam enables the resolution of smallest targets or changings of the measurement object. Due to its high resolution it can resolve small scale contours in a measuring range from 2 cm up to 15m. The small size of the sensor enables even the use in very small scale applications or at applications with challenging placement or mounting requirements.

Application range

From 2 cm to 15 m in water.

Data acquisitions

The measured distance is directly shown on a four digit display and the proportional analogue 0-10V output voltage at a BNC socket allows the integration into external data acquisition.

Specifications

Measuring rate	Max. 10 Hz
Resolution	1% of the measuring range
Temperature range	-20 to +70 °C
Output	BNC-Socket, 0-10 V
analogue with zoom-function	

3.2 Definition of time origin and instrument synchronization

The Wave generator Acquisition System (WAS) controls the time frame of the experiments. The WAS files start to record the equipment activities usually around 10-20 seconds before the wave paddle starts its movement (the wave generation). At the moment of starting waves there is a trigger signal sent to start other equipment and recorded on the WAS file. The WAS system controls the acquisition of all the CIEM equipment (WGs, AWGs, PPTs and synchronization signals

of other equipment) at a frequency of 40 Hz. The only equipment from the CIEM which is not recorded on the WAS files comprises both LCs and PSs which need to be recorded in an external computer in order to save the digital information. LCs and PSs are usually set to measure at 2400 Hz and they have their own time frame which is correlated with the WAS by mean of the TTL trigger signal that starts the LCs+PSs acquisition. The TTL signal generated at the wave generation is a trigger signal that goes from 0 to 5 V, stays at that voltage for 5 s, and then drops from 5 to 0 V.

4 Data post-processing

The raw signals from PPTs, LCs and PSs needed to be treated and corrected.

4.1 PPTs correction

A MatLab subroutine was employed to correct a detrended sea surface time series for depth attenuation. Frequency correction from 0.05 to 0.33 Hz. The subroutine was written by Urs Neumeier, 2003-2004 and modified from by T. Mason, SOC, January 1997.

4.2 LCs and PSs

A MatLab subroutine written by Maximilian Streicher (Ghent University) in 2017 and modified by Corrado Altomare in 2021 has been used for data filtering. First, any long duration drift was removed from the signal using the 'detrend' functionality. Besides, an offset correction was applied, by fitting a polynomial best-fit line to the lower values of the time-series (the noise band, not including the force peaks) and subtracting the polynomial best-fit line from the time-series. The time-series was then transformed into frequency domain with FFT. In frequency domain the filters were set, to remove phenomena related to model effects (for example electronic current frequency, natural frequency of the measurement system) from the time series. A band-stop filter was used. For LCs, a low-pass filter was also employed to stay below the natural period of the measurement system. A Butterworth filter design of 4th order was used. Similar procedure is described in Kortenhaus et al. (2019).

4.2.1 Summation of LC results

The filtered time series from LCs 1 to 4 were summed to obtained the total vertical force acting on the pier platform. The filtered time series from LCs 5 and 6 were summed to obtained the total horizontal force acting on the pier platform.

5 Test program

The number of tests carried out in the CIEM flume is equal to 224. Focused wave groups were generated. Each focused wave group time series was created using the NewWave theory as described in Whittaker et al. (2017).

The range of target wave conditions is summarized as follows (expressed in model scale):

- maximum wave height at the focus location ($H_{\max}$): 0.65 – 1.11 m
- distance of the focused from the wave generator: 48.16 – 55.11 m
- phase of the focused: 0 – 270 °
- water depth at the wave generator: 2.435 – 2.52 m
- water depth at the pier toe: 0.815- 0.9 m
- pier clearance: 0.415-0.5 m

The range of measured wave conditions at the WG8 location are (expressed in model scale):

- maximum crest elevation ($\eta_{\max}$): 0.31 – 0.77 m
- maximum wave height ($H_{\max}$): 0.62 – 1.04 m
- wavelength at the toe associated to the highest wave: 8.36 – 11.57 m

6 Organization and structure of data files

All data files are stored in a local hard drive at UPC. To access and receive the data, contact Dr. Corrado Altomare (email: corrado.altomare@upc.edu). The data is structured as followed:

- Directory “**DATA**” comprises:
 1. File “03_RESULTS.txt”: file with information on the maximum target and measured wave characteristics for each test case;
 2. File “04_PEAKEs.txt”: file containing all results of force peaks for each test case
 3. **Test directories** with water surface elevation time series (raw data), categorized per date (**DATE=GGMMAA**), containing the data acquired during each test case. Each directory includes several test cases. Each test case name is coded employing the DATE followed by “_##_conv.txt”, being **TESTID=GGMMAA_##**).
 - Subdirectory **Perfils**: it contains an Excel file with the results of the beach profile measurements and corresponding measurement dates.
 - Subdirectory **LC_PS**, located inside the folder TESTID and containing the files of LCs and PSs measurements (raw data).
 - file **TESTID.TSX**: metadata for LC and PS data;
 - file **TESTID.asc**: LCs and PSs measurements (raw data).
 4. Directory **_RESULTS** containing a subfolder for each test case. The subfolder name is coded as follows: “**Case_TESTID**” and contains the post-processed data for water surface elevation and forces, in particular:
 - File “ETA.mat”: MatLab data file with post-processed signals from WGs, AWGs and PPTs and sensor locations.
 - File “F.mat”: MatLab data file with the resultant and filtered time series of forces (4 columns: Time, Total Horizontal Force on the Platform, Total Vertical Force on the Platform, Horizontal Force on the Pile Cap);
 - Figures (both in .fig and .tiff format) from the analysis of water surface elevation signal.
 5. Directory **Media**: it contains several subfolders with videos of the tests. They are organized per date and test number.

In Table 6-1 the output file format for each measurement device is given.

Table 6.1: Output file specifications

Data file	Type	# heading lines	Column: Instrument [Unit]	Comments
TESTID.TSX	TypeScript	-	-	Metadata of load cells acquisition
TESTID .txt	ASCII	1	Time_LC[s] LC1[kg] LC2[kg] LC3[kg] LC4[kg] LC5[kg] LC6[kg] LC7[kg] SYNC[V] Time_PS[s] PS7[Pa]	Sampling frequency 2400 Hz

			PS1[Pa] PS8[Pa]	
TESTID _conv.txt	ASCII	6	DEMAND[m] FEEDBACK[m] WG0[m] WG13[m] WG2[m] WG3[m] WG7[m] WG4[m] WG5[m] WG6[m] WG8[m] WG9[m] AWG0[m] AWG1[m] AWG2[m] AWG3[m] AWG4[m] AWG5[m] AWG6[m] AWG7[m] AWG9[m] PPT0[m] PPT1[m] PPT2[m] PPT3[m] PPT5[m] PPT6[m] PPT7[m] PPT8[m] PPT9[m] PPT11[m] PPT12[m] PPT13[m] SYNC_PXI1[V] SYNC_PXI2[V] SYNC_PXI3[V]	File with converted data of water surface elevation and wavemaker displacement. Sampling frequency 40 Hz. Notice that PPT7 was not measuring.

7 References

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