Submerged flexible circular porous structures in currents and waves

FLEXISTRUCT

CIEM,Universitat Politècnica de Catalunya

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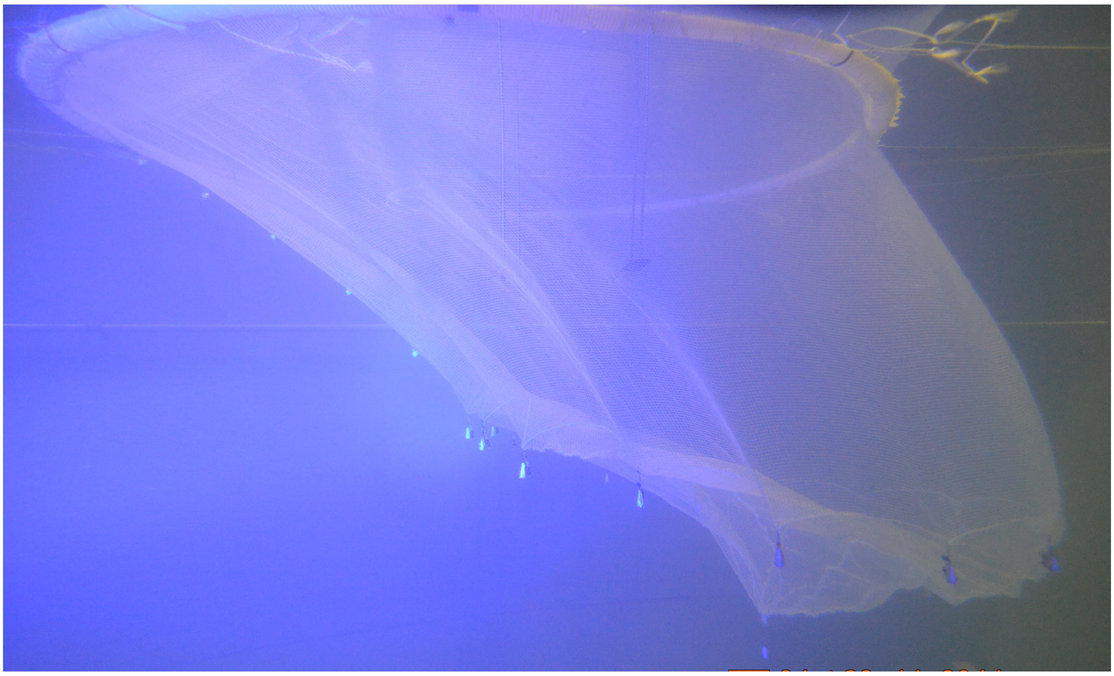

Infrastructure	CIEM		
Project	Submerged flexible circular porous structures in currents and waves		
Campaign	HyIV-CIEM-05		
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1. Relevance and Scientific aim and background

Moving operations to areas where currents and waves are large can reduce the environmental impacts of modern fish farming, yet introduce challenges for the cultured fish including swimming in the currents and in reduced cage volumes resulting from net cage deformations. Fish welfare is highly dependant on both internal volume of the net structure and the currents. The main objective of this project is to study the fluid structure interaction that occurs when a flexible, structure like a net cage is immersed in a flow with waves. The aim is to get a better understanding of the response of flexible porous structures under intense and extreme loadings, and find benchmarks to improve the ability to model such interactions numerically.

Most structures in nature are flexible and manage to deal with flows: for example leaves by changing their shape will maximize their surface area in order to capture an optimum sunlight (Vogel 2009). Any large body anchored in a flow, will generate vortex shedding in its wake: these vortices will interact with the body and change the loading on it. This problem becomes more complicated when the body is flexible.

Drag reduction by reconfiguration. The research will focus on the deformation of flexible structures in currents and waves. The physics to be studied are similar to the mechanism of reconfiguration of broad leaves subjected to wind loading (Schouveiler &Boudaoud 2006): the shape of the structure changes when the velocity increases or when the structure stiffness decreases. This reconfiguration leads to a decrease in the drag coefficient, and it is clearly shown by Vogel (1989) and Gosselin *et al*. (2010), that the drag growth with velocity for a flexible bluff body is much slower than the classical ridgid body law, $F \propto U^2$, where F is the drag force and U is velocity. Vogel proposed $F \propto U^{2+\vartheta}$, where ϑ is the *Vogel exponent*. The only published work on this topic (Lader & Enerhaug 2005) showed that the drag on net structures does *not* increase as U^2 due to flexibility, but in this study no waves were involved.

Dimensional analysis. Dimensionless numbers obtained from dimensional analysis are very useful for scaling purposes and for organizing experimental model tests and numerical calculations to avoid unnecessary repetitions. The importance of non-dimensional ratios like *Reynolds, Froude* and *Cauchy* numbers will be investigated. The latter characterizes the deformation of an elastic solid under the effect of the flow (De Langre 2008). A *dimensionless reconfiguration number*, which accounts for the effect of flexibility on the drag by comparing the drag of the flexible plate to that of a rigid one of the same geometry, has been proposed by Gosselin (Gosselin *et al*. 2010).

Effect of waves and currents on a net cage. Nearly all cages used in exposed areas in the Norwegian salmon farming industry are of the *"gravity"* type . These cages have a surface collar structure from which a net is hung. Gravity cages do not have rigid nets and 'bagging' deformation occurs in strong currents and decreases the total cage volume. Cages deform in currents largely by a deformation of the front and back walls, and thereby also lifting the bottom netting (Aarsnes *et al*. 1990). As reported by Lader *et al*. (2008), current speeds of 0.13 - 0.35 m s^{-1} at two full-scale farms caused cage volume reductions of up to 20- 40% and resulted in the cage bottom being lifted significantly. In extreme cases, where nets are severely deformed during storms that generate currents >1 m s^{-1}, mass mortalities of up to 40 tonnes of fish in a cage have occurred. Flow through and around a cage is influenced by factors such as cage design, cage layout, fish movements, flow conditions at a site and local topography (Klebert *et al.* 2010), but descriptions of these patterns and their correlations have not been field-tested with enough detail to provide useful benchmarks. Numerical simulations and small-scale laboratory tests show that current speed and net porosities can affect the internal hydrodynamics of sea-cages (Shim *et al.* 2009; Gansel *et al.* 2010).Norwegian classification system of degree of environmental exposure for fish farm sites, using significant wave height (H_s), wave spectral peak period (T_p) and current (V_c) (Table 1).

Table 1 : Norwegian aquaculture site classification scheme for waves and currents

Wave	H_s (m)	T_p (s)	Degree of exposure		Current	V_c (m/s)	Degree of exposure
A	0.0-0.5	0.0-2.0	Small		a	0.0-0.3	Small
B	0.5-1.0	1.6-3.2	Moderate		b	0.3-0.5	Moderate
C	**1.0-2.0**	**2.5-5,1**	**Medium**		**c**	**0.5-1.0**	**Medium**
D	**2.0-3.0**	**4,0-6,7**	**High**		**d**	**1.0-1.5**	**High**
E	**>3.0**	**5.3-18.0**	**Extreme**		**e**	**>1.5**	**Extreme**

We will study sea-cage hydrodynamics through lab experiments (scaled) and verify numerical models of the internal hydrodynamics and deformations of full-scale cages in the medium to extreme environmental classifications for waves (C-E) and currents (c-e).

Main objective of these experiments : To investigate the different mechanisms involved in the deformation of flexible structures in currents and waves. The focus is on the vortex interactions in the wake and the internal hydrodynamics in the living space of the cage.

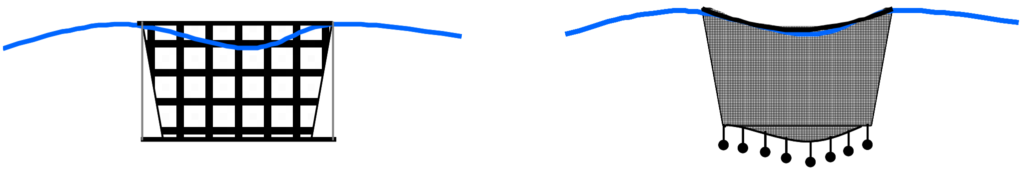
Approaches, hypotheses and choice of method: Experiments with simple structures has been conducted prior to those at CIEM. Four types of simple structures (flexible plates, flexible porous plates, flexible membranes and nets) have been tested in a small-scale wave flume in Trondheim, Norway . The effects of surface porosity on the hydrodynamic forces and deformation of flexible structures, using similarity analysis, is still under study. The experiments have been used to determine the appropriate porosities and flexibilities to design the net cages for the experiments at CIEM.

Objective of the experiments at CIEM: To get a better understanding and details of the flow patterns inside and outside a cage in waves and currents to provide useful benchmarks for numerical models.

Background and Problem: Different hydrodynamic load models have been used to calculate the drag and lift forces, and the wake behind structures in fish farms (Aarsnes *et al.* 1990; Løland, 1993), but square cages have been used in this work. Numerical models to calculate the flow field upstream and inside a cage have been developed (Fredheim *et al.* 2003) but are not practical for large net cage systems. More recently, the complexity of flows around single porous cylinders has been studied experimentally (Harendza *et al.* 2009; Gansel *et al.* 2010). Experiments on the interaction between waves and a cage have also been performed, but due to a limited number of measurements, an accurate description of the flow inside and outside the cage is not available.

Research and Solution: We planed laboratory experiments to study the effects of wave height and period and current speed on the internal and external hydrodynamics of cages. During tests, cage drag and deflection of the bottom rim have been measured with pressure gauges and underwater cameras. A sinker tube deployed from the surface collar has been be attached to the lowest portion of the net, a solution currently used to reduce bagging deformations (Figure1.a). Flow patterns inside and outside the cage has been recorded with the available sensor systems at CIEM. Three different cage sizes have ben tested to verify similarity and determine if cage design plays an important role in the flow pattern. The weight of the sinker tube is also a parameter during these experiments as it will affect the total volume of the cage, the flexibility and, depending on the frequencies and heights of the waves, the behavior of the cage.

A heavy weight sinker tube will make the total structure more rigid and so less compliant to follow wave shape (Fig. 1a), as opposed to separated weights (Fig. 1b). This will affect the flow in the cage: all configurations tested are in figure 11.



a) **b)**

Figure 1 : influence of the bottom design: a) weight sinker tube, b) separated weights.

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2. **User-Project Achievements and difficulties encountered**

Most of the measurements planned during the preliminary meeting were carried out during the experimental campaign.

a) The main difficulty encountered were the time required to change the cage model as each time the tank as to be emptied in order to allow an easy access to the cage fixation points. This method has been chosen due to the high number of sensors (ADVs, Wave gauges, load cells) located around and in the cage. Trying to switch different cages with a tank full of water could have led to incidents which could had damage all these expensive sensors. The bottleneck of this procedure is that only one cage was able to be tested per day.
b) The buildup of all the experimental setup took more time than expected: this may be due to the complexity of the experiments; Indeed time was required to buildup the scaffolding which supports all the sensors in specifics positions and the floating cage itself.

3. **Highlights important research results**

The elaboration of the data acquired during the experiments are in progress, therefore we cannot highlights important research results up to now. But as a first major result of these experiments it can observed that the cage design1 (figure 11) offers a better alternative in terms of volume reduction while the design is the one undergoing large volume reduction.

4. **Publications, reports from the project**

For the same reason reported in section 3 there are not publications from the project up to now. But it is planned to publish in journals related to offshore, coastal and aquaculture engineering disciplines which are the potential end users of this project. Communication will be done through recognized scientific peer-reviewed journals as *Journal of Fluid Engineering*, *Journal of fluid and structures*, *Journal of Sound and Vibration* on the following topics: a) Effect of the porosity on the drag and deformation of simple flexible structures. b) Effect of the porosity on the drag and deformation of net cages. c) Internal cage flow patterns subjected to waves with different frequencies and heights

5. Description

5.1. General description, including sketch

The fish net cage is placed in the CIEM flume Wave tank. Waves are generated at the wave paddle. Interaction between waves and the structure takes place The displacement of the waves as they propagate along the tank are recorded through 13 wave gauges : 8 gauges have been disposed in fron of the net cage , one in the cage and 4 on the wake of the net cage. In addition there are 7 ADVs (Acoustic Doppler velocimetry) which record the velocity field around and in the cage and also on its wake.

At the end of the flume, a dissipating parabolic beach prevents reflection of waves back towards the structure. Figure 2 shows the positions of the 13 wave gauges(WG) along the flume tank. The Wage gauge 9 is placed exactly in the middle on the cage . In this figure the absorbing beach is not represented.

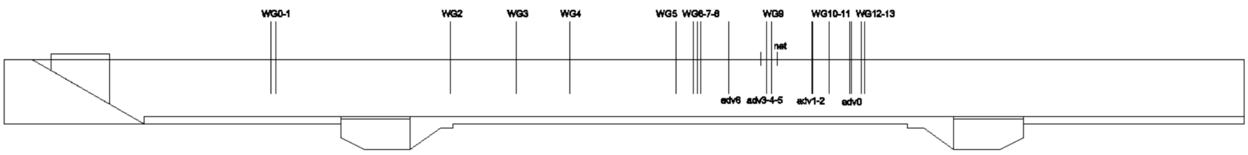

Figure 2 : Positions of the 13 wave gauges along the flume tank

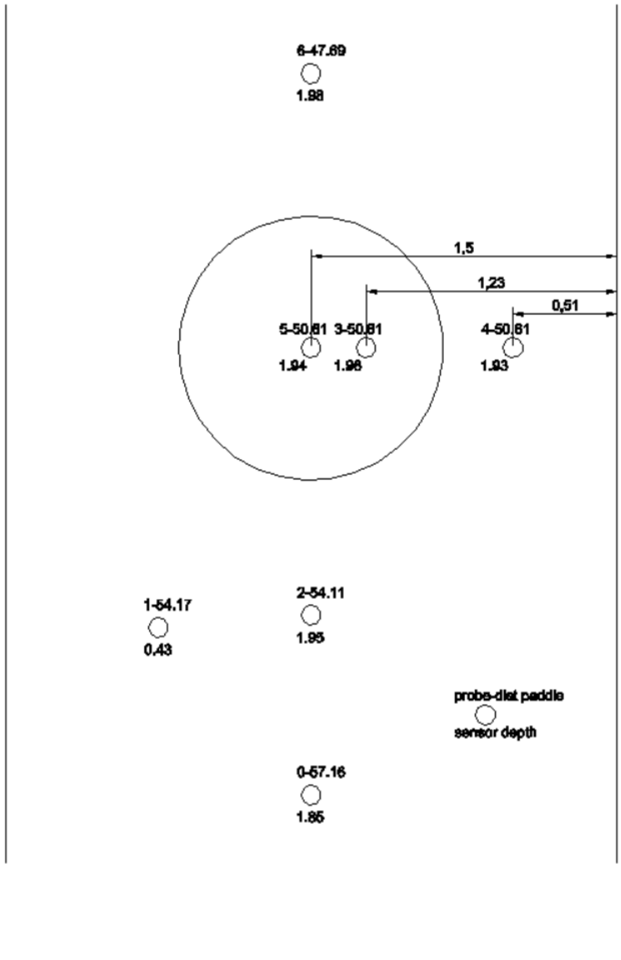

Figure 3 :Positions of the 7 ADV sensors Around the net cage

Relevant fixed parameters

The water depth is kept constant at h = 2.3m during all tests.

Measured parameters

We measured the time series of the drag force on the net cage, time series with the current velocity field in different locations around the net cage and times series of the wave propagation along the flume. Video is used to capture events in the vicinity of the net cage .

Data post-processing

In order to remove the noise in the signal from the ADV (due to the lack of particles in the water), a simple filtering has been performed during the post processing trough some MATLAB scripts

5.2.Definition of the coordinate system used

The origin is positioned at the wave paddle, on the back side of the flume, at the bottom. The horizontal x-axis is positive in the direction of wave propagation towards the structure. The horizontal y-axis is positive along the wave paddle towards the front side of the flume. The vertical z-axis is positive upwards.

5.3.Instruments used

5.3.1 ADV (description given by CIEM)

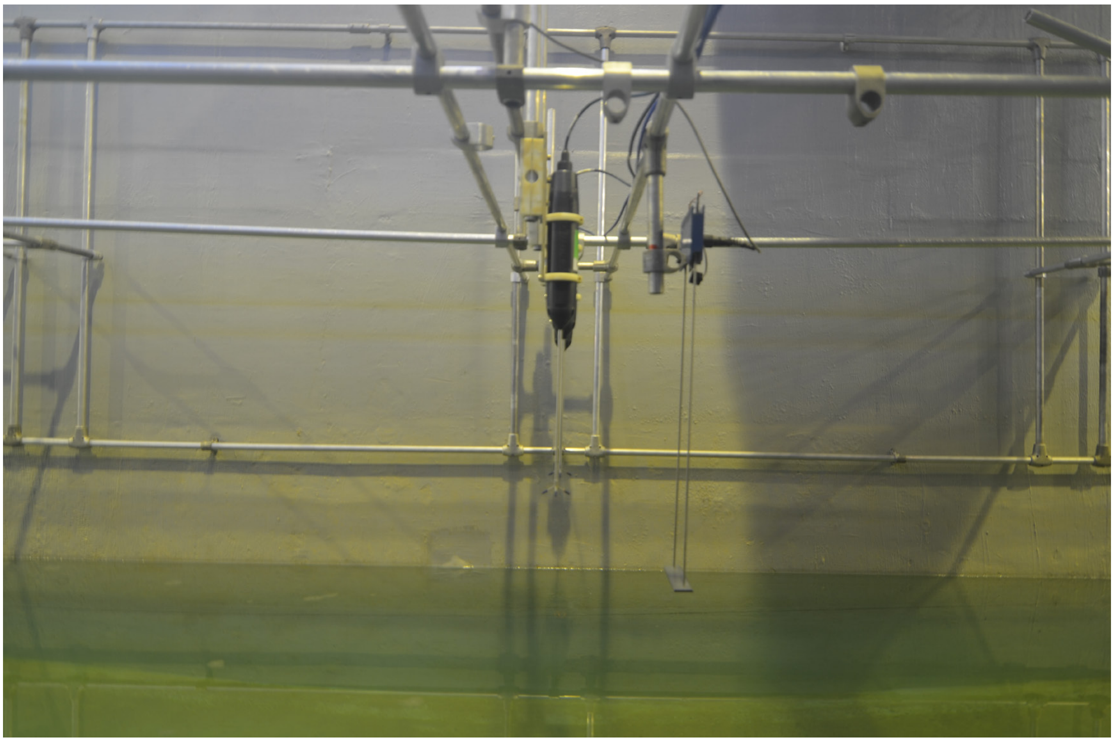
Figure 4 : Picture of the 2 ADVs located inside the cage(R) and wave gauge(L)

The Vectrino velocimeter from NORTEK measures water speed using the Doppler effect.

The probe consist of four receive transducers, each mounted inside the receiver arm, and a transmit transducer in the centre. The Vectrino uses the Doppler effect to measure current velocity by transmitting short pairs of sound pulses, listening to their echoes and, ultimately, measuring the change in pitch or frequency of the returned sound. Sound does not reflect from the water itself, but rather from particles suspended in the water (zooplankton or sediment). Every probe has a temperature sensor. Technical specifications can be found at http://www.nortek-as.com/en/products/velocimeters/vectrino

Calibration

To calibrate the probe there is a probe check feature within the Nortek software. This has been designed to act as a measurement quality assurance tool, by letting inspect the region where the Vectrino makes its measurements and showing how the signal varies with range.

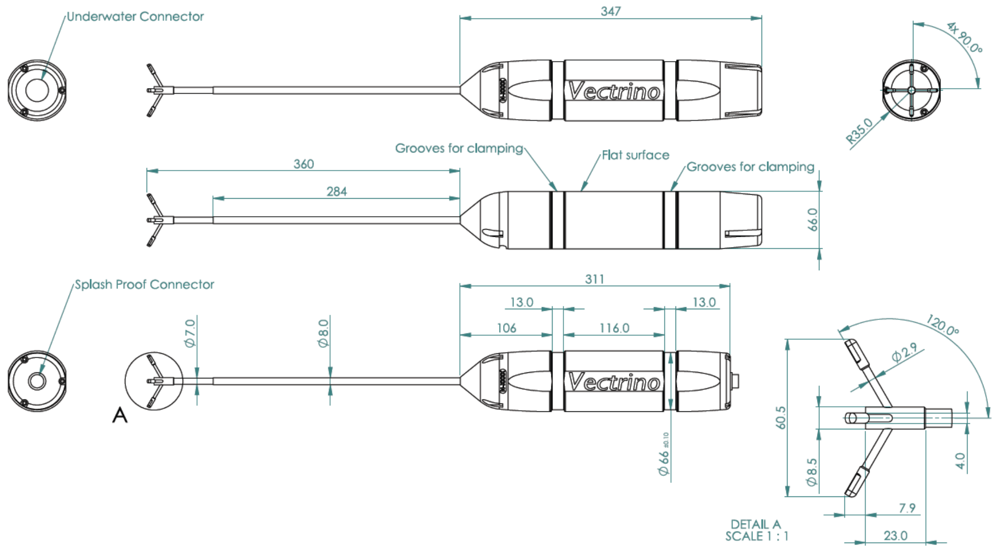

Figure 5 : Vectrino used druing he experiments (Picture from NORTEK)

Data acquisition

Due to the fact that seven ADV have been placed during these experiments the data acquisition of all this information has been done by using the Nortek software. This software allows the synchronization of the measuring ADV and the data synchronization of the acquired information. The information is stored in .vno extension files that later on the program transform to several files (up to 6), from which the date, temperature, velocities, correlation of the signals, intensity of the signal can be easily recovered for every probe.

5.3.2 Resistance wave gauges (description given by CIEM)

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 Load Cells. All these gauges were calibrated every day prior each experiments.

5.3.3 Load cells (description from FUTEK)

Two Loads cells were used to measure the drag force on the cage through some mooring lines on the front and back of the cage. These loads cells are The S-Beam Jr. (LSB200) from FUTEK, It is a Miniature Load Cell that is able to measure compression and tensile forces in the range of 10 grams to 100 lbs (444 Newtons). These cells are waterproof and very small so induce less disturbance to the flow. The technical characteistiques of these load cells can be found at http://www.futek.com/product.aspx?stock=FSH00091&acc2=acc#productDescription

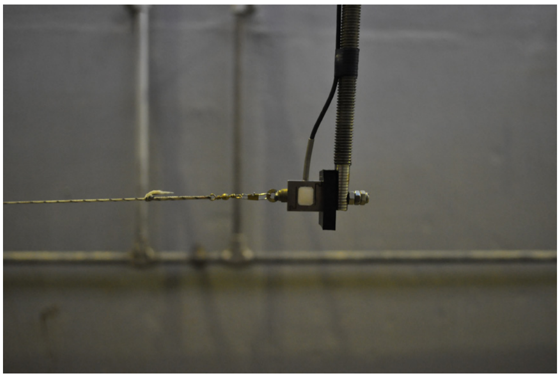

Figure 6 : Picture of the load cell (LSB 200) located on the back of the cage

5.3.4 Underwater Camera

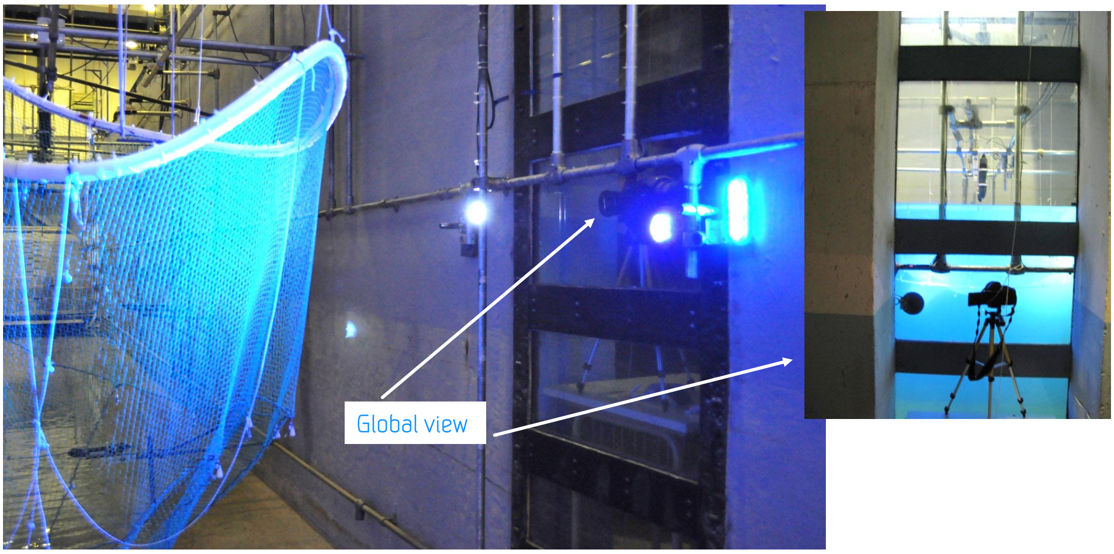

Figure 7 : Picture of the underwater cameras and LED lights and the outside camera

Two mini undertware camera together with LED Spot lights were placed along the wall of the tank in front and in the back the cage . It gave information about the deformation of the cage submitted to current and waves.

5.4. Wave conditions and disposition of the instrumentation along the flume

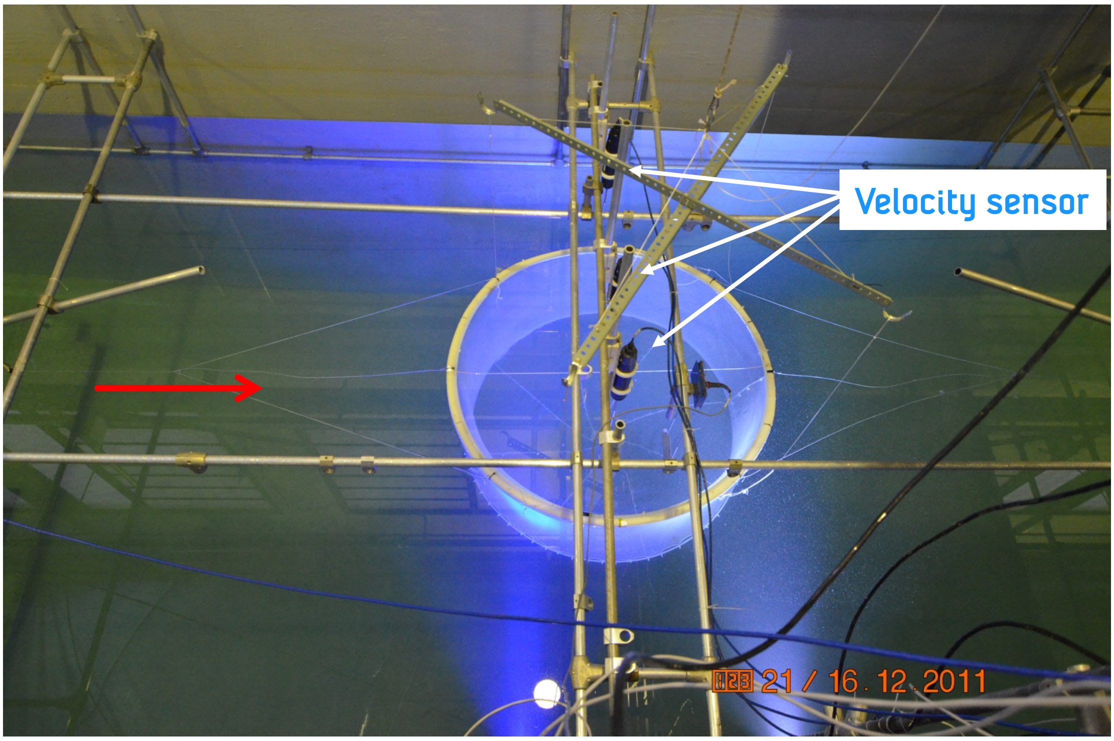

Figure 8 : Picture of the cage in the tank and the sensors mounted at the scaffolding

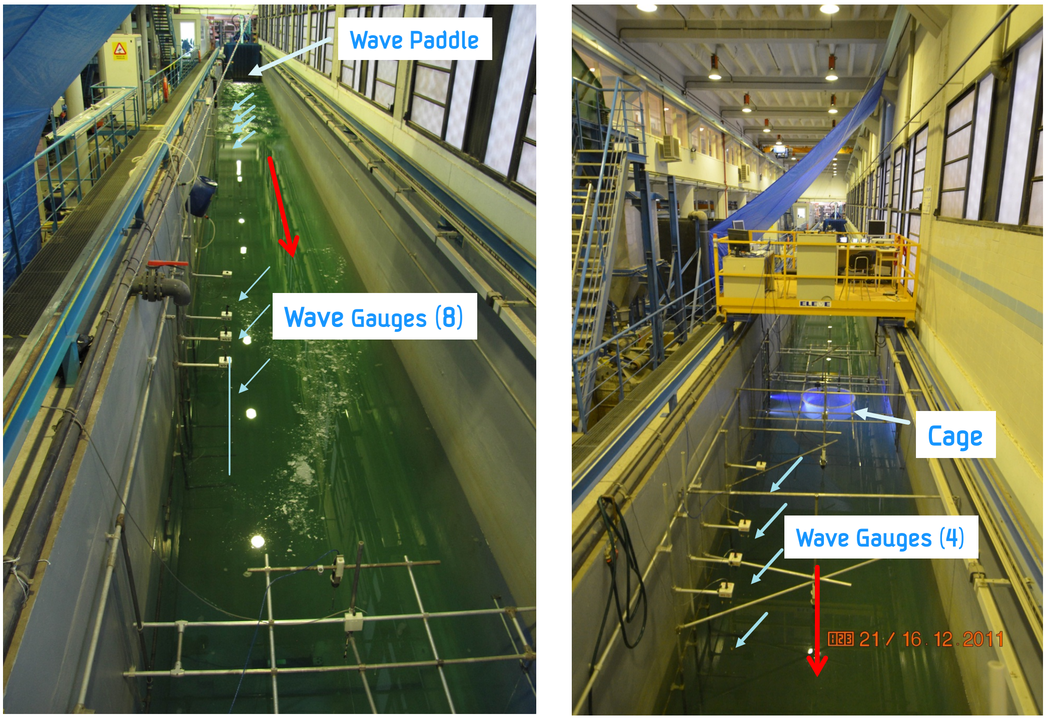

Figure 9 : Picture of the tank in front(R) and back(L) of the cage and the 12 waves gauges

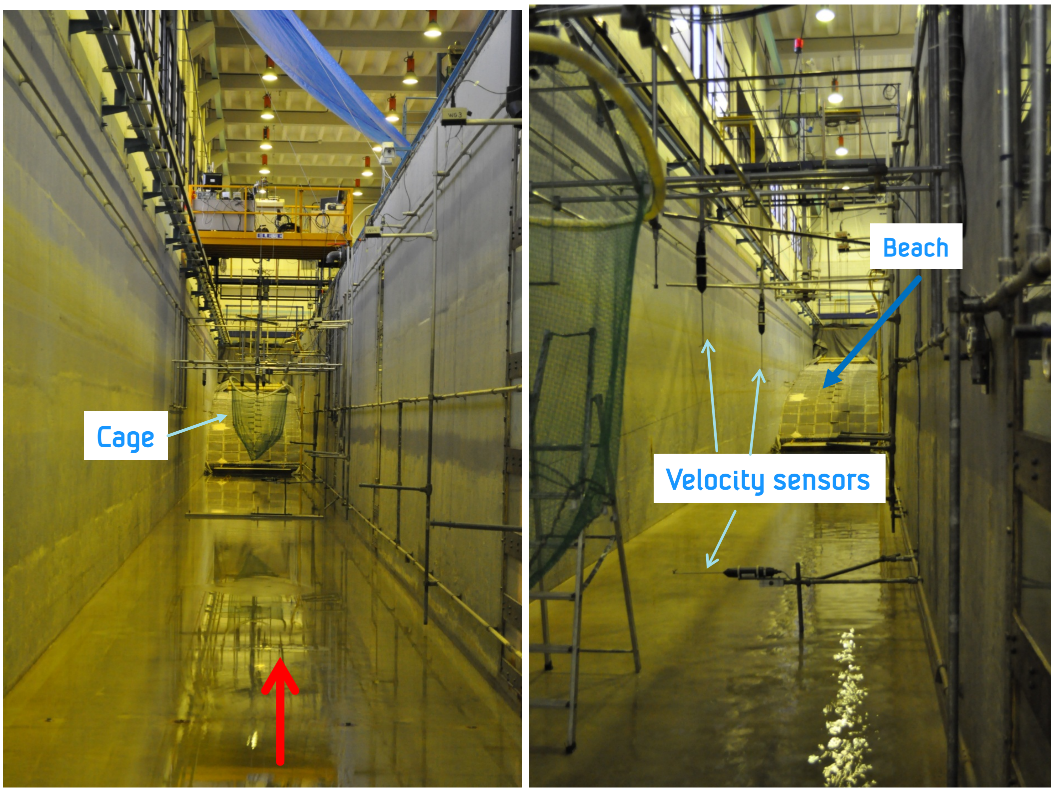

Figure 10:Pictures of the tank and the cage from the wave padle (R) and to the beach (L)

5.4.1 Instrument Disposition Agenda

A total of 13 wave gauges are used, positioned around the net cage. There 7 current flow velocity sensors (Acoustic Doppler velocity : ADV) and 2 pressure gauge sensors. During the tests, regular video (25fps) and pictures are used to capture events around the net cage.

The positions of the wave gauges, ADVs and pressure gauges with respect to the position of the wave paddle are listed in Table 2, 3 and 4.

Table 2 : **Positions of the wage gauges**

Wave gauge	Distance from the paddle(m)
1	12,41
2	12,75
3	26,25
4	31,32
5	43,62
6	44,95
7	45,27
8	45,54
9	51,00
10	55,41
11	57,0
12	57,9
13	58,16

Table 3 : **Positions of the ADVs**

ADV	Distance from the paddle (m)	Distance to the wall (m)	Depth (m)
0	57,16	1,5	1,85
1	54,17	2,5	0,43
2	54,11	1,5	1,95
3	50,81	1,23	1,96
4	50,81	0,51	1,93
5	50,81	1,5	1,94
6	47,69	1,5	1,98

Table 4 : **Positions of the pressure gauges**

Pressure gauges	Distance from the paddle (m)	Distance to the wall (m)	Depth (m)
1	49,3	1,5	2,25
2	52,7	1,5	2,25

Definition of time origin and instrument synchronization

Readings of all instruments are logged with one data acquisition system. The system takescare of synchronization. The readings are sampled with 20Hz. Data logging starts before the moving of the wave paddle.

The video and camera data is not synchronized with the other instruments.

Experimental procedure and test program

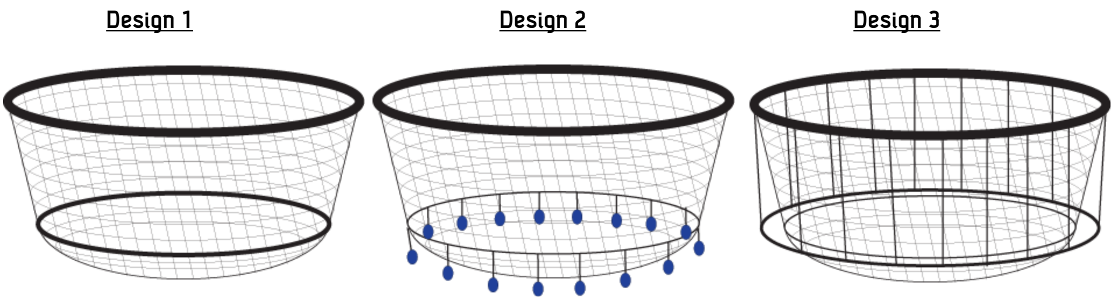

Figure 11: **Net cage designs tested**

The figures 11 shows the kind of the net cage designs that were used during the experiments. The weight at the bottom is always the same during the tests; it is in fact just the way how it is distributed and hanged on the cage which differs. In addition different porosities (and so the solidities) have been tested during the tests.

Each day one net cage has been tested due to the time needed to change and install a new net cage in the flume; For each test a excel sheet is written: it contains the settings of the wave paddle (T: period and n: number of waves), relevant observations made during the tests if required and the name (based on the date of the experiment and the specific time when a test is conducted) of the acquisition files generated during each test : two files, containing all the measured parameters are generated during each experiments . In this Excel sheet , for each current velocity the following information is written :

Table 5 : Waves Characteristics

T(Period of the waves in s)	N(number of waves)	Fitxer CIEM	fitxer ADV
0 -1.2- 1.5	30 - 40	Filename of the 13 Wave and 2 pressure gauges time series	Filename of the 7 ADVs time series

The current velocities tested during these test are 0, 4, 8, 11, 15, 20 cm/s . However for some tests it was not possible to run all these velocities (high values) due to the high deformation of the net of the cage which could have impact and so damage the ADVs sensors located in the cage.

A test starts with an initial free surface at rest. The data acquisition system is started before the wave paddle starts moving. When the duration of the test is over the data logging automatically stops and then the wave paddle is stopped. Only regular waves have been used.

The organization for the files is quite eased as each day of experiments only one net cage design has been tested. In total 9 different net cages (combination of designs, porosities, depth) have been tested. The rest of experimental time has been allocated to build the specific setup to support the net cage at a specific location in the flume and the calibration of all the sensors.

As the experimental program was quite heavy the table below groups the main features of the full test program

Table 6 : daily test programme (for each of the 9 tested cases)

Case	Velocity (m/s)	Waves height (cm)	Period (s)	n (number of waves)
1-9	0, 4,8,11,15,20	12	1,2	40
1-9	0, 4,8,11,15,20	15	1,2	40
1-9	0, 4,8,11,15,20	12	1,5	30
1-9	0, 4,8,11,15,20	15	1,5	30
1-9	0, 4,8,11,15,20	20	1,5	30
1-9	0, 4,8,11,15,20	25	1,5	30
1-9	0, 4,8,11,15,20	30	1,5	30

So in total , as this test matrix has been performed for each case and each current velocity , a **total amount of 378 tests** have been performed but some of them have been aborted due to high risk of impact of the net of the cage to the ADVs sensor located in the cage.

Table 7 : List of the performed experiments

Date	Case
23.11.2011	Calibration
28.11.2011	Short Cage Sn=0,319 Design 3
29.11.2011	Short Cage Sn=0,319 Design2 (Currents)
12.12.2011	Calibration
13.12.2011	Long Cage Sn=0,319 Design2
14.12.2011	Short Cages Sn=0,319 Design1
15.12.2011	Short Sn=0,319 Design2
16.12.2011	Long Cage Sn=0,319 Design1
19.12.2011	Long Cage Sn=0,1072 Design3
20.12.2011	Long Cage Sn=0,1072 Design1
21.12.2011	Long Cage Sn=0,319 Design3
22.12.2011	Long Cage Sn=0,1072 Design2

6. Organisation of data files

The data files that contain the readings of the instruments are in ASCII format. There are 2 kind of files : One for the ADV (Velocties) and the other one for the 13 waves gauges and the 2 load cells .
The naming of these files are as follows:

For the ADVs : [year][month][day][hour].vno (for example 201112201032.vno).
These files have been converted and spited into readable files (ASCII files) by the provider into different (*.amp, *.cor ,*.ctl,*.snr,*.tem,*.vel)

As example we just show the format of the file with the velocities (*.vel)
Velocity cm/s
Probe SampleTime Event Counter X (1) Y (2) Z (3) W (4)

The vales that are used for the plotting are X (1),Y (2),Z (3) and the time columns .

For the wave gauges and load cells files :[day][month][last2digitof theyear]_[number of the test].conv (for example 201211_1)

The first 5 lines are just general information and the used sampling rate

[Info]
Sample Rate=40
Creation=
Changes=
[Data]

Then all the data are listed in columns
DEMAND(m) FEEDBACK(m) WG0(m) WG1(m) WG3(m) WG4(m) WG5(m) WG6(m) WG7(m) WG8(m) WG9(m) WG10(m) WG11(m) WG12(m) WG13(m) LOAD1(Kg) LOAD2(Kg) LEVEL(m) SYNC(V)

Only the columns WG0(m) till WG12(m) and LOAD1(Kg) and LOAD2(Kg) are used in our case.