Θαλάσσια Υδραυλική και Λιμενικά Έργα

Ειδικά θέματα Λιμενικών Έργων: Αγωγοί Ανανέωσης

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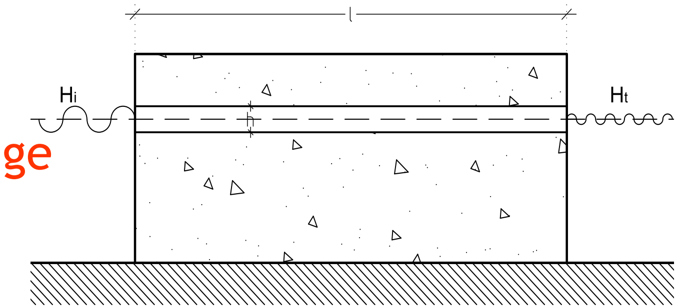
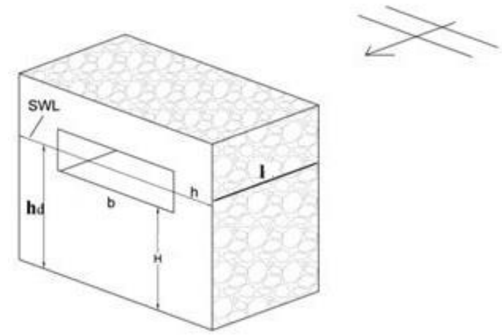
Flushing Culverts

- Water quality within the basin preserved water periodic exchange between harbour and open sea
- placement of ***flushing culverts*** across the breakwaters
- The axis of the culverts, in regions where the ranges of tides are low (e.g. the Mediterranean), is constructed at the sea water level
- ***Flushing culverts*** allow water recirculation:
  [+] ensure water quality

  [-] increase the wave disturbance into the basin (problem with: *navigation, mooring of vessels*)





Vertical-front breakwater bearing a flushing culvert

Marina Kalamata

Αγωγοί Ανανέωσης στον Ελλαδικό χώρο

- 600 λιμάνια στην Ελλάδα, ανάγκη για αγωγούς ανανέωσης
- Επικρατεί η ανεμογενής κυκλοφορία των υδάτων ➔ διαμήκης άξονας στη στάθμη ηρεμίας ύδατος

Κυματοθραύστης με αγωγό ανανέωσης στην Καλαμάτα.

Κυματοθραύστης με αγωγό ανανέωσης στο Μάτι.

Αγωγοί ανανέωσης στη Μυτιλήνη.

Flushing Culverts

- Designing a flushing culvert ➔ good understanding of the hydrodynamic :
  - *partial reflection*
  - *diffraction*
  - *production of evanescent modes*
  - *wave breaking*
  - *generation of higher order harmonics*

- Main non-dimensional parameters concerning the water quality within the harbour basin ➔ the wave transmission coefficient, $\mathbf{K_t}$

$$K_t = H_t/H_i$$

H_t :transmitted wave height through the flushing culvert

H_i :incident wave height

- The K_t is correlated with:
  - *the wave characteristics*
  - *the geometrical characteristics of the culvert*
  - *the water depth*

Numerical Methods

- Boussinesq models not appropriate as they assume a depth-average velocity profile → does not allow the detailed description of the evanescent modes that arise due to the abrupt changes in water depths.
- Boundary element methods (BEM)→ good … in the isolation of each harmonic
- Reynolds Averaged Navier–Stokes RANS → … and change in mean water level
  - Volume- Averaged - (VA)RANS e.g. Garci… andLiu,1998)
  - Large Eddy Simulation (LES) e.g. Losada …

> - Computationally expensive
> - Understanding of physics rather than investigate the effectiveness of FCs

- 2D linear coupled-mode system Athanassoulis & Belibassakis (1999)
- extended to second-order Belibassakis & Athanassoulis (2002)
  - Limitations concerning nonlinearity of the wave field & as the culvert width decreases
- 3D linear coupled-mode model, based on eigen-functions expansions of the Laplace equation Belibbasakis, Tsoukala & Katsardi (2014)
  - Much improved compared with 2D concerning diffraction but again limitations concerning nonlinearity

The development of Artificial Neural Networks-ANNs

Tools that combine the experimental results with some kind of error correction algorithm ➔ accomplish a more accurate prediction of the target value

- Van den Boogaard et al. (2009) ➔ numerical model, powered by a limited number of experimental measurements - calculate the loads exerted on the toe of breakwaters under critical wave conditions

Closer to the present work:

- Panizzo and Briganti (2007) ➔ ANN fed by a large number of experimental measurements, estimating wave transmission coefficient over low-crested structures
- Castro et al. (2011) ➔ investigated the reflection coefficient of submerged breakwaters by using ANN
- Chondros and Memos (2012) ➔ ANN based on a small experimental database & a Boussinesq-type model - derive a compound tool for prediction of wave transmission coefficient over submerged breakwaters

Semi- empirical Formulas

Tsoukala et al. (2010) - experimental measurements, were carried out in the wave flume at the Laboratory of Harbor Works at the National Technical University of Athens

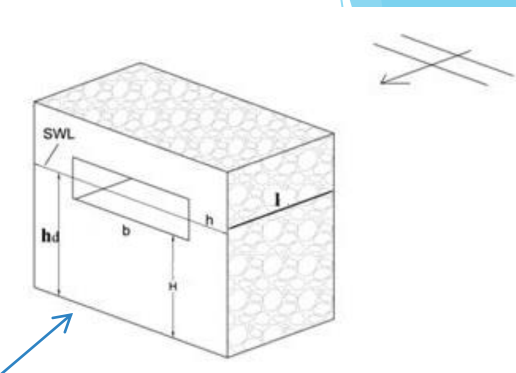
$$K_t = \frac{H_t}{H_i} = \left(0.135\frac{b}{H_i} + 0.048\frac{2h_s}{H_i} 0.030\frac{h_f}{H_i}\ 0.026\frac{d}{H_i} 0.036\frac{l}{H_i}\right) * \mu^{-0.681}$$

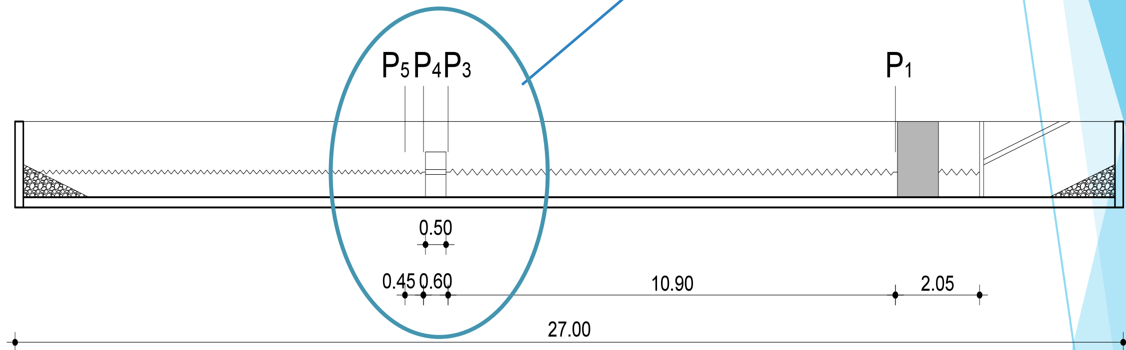
h_f: the water depth at the toe of the flushing culvert
b: the width of the flushing culvert
h_s: the half of the height of the flushing culvert
d: the water depth
l: the length of the flushing culvert
H_i: the incident wave height
T: the wave period
tana: the breakwater's slope
$\mu = \sin\alpha / \sqrt{2\pi H_i / g T^2}$

Experimental Data

2D and 3D experimental facilities

Giannaki (2005), Tsoukala et al. (2010) and Chondros et al (2014)





The <u>2D wave flume</u>:

- 27.00 m long
- 0.60 m wide
- 1.53 m depth

The scaled *breakwater* with a vertical forehead:

- 1.00 m height
- 0.50 m length
- 0.60 m width

- 0.60 m water depth

Side-view of the wave flume and the experimental setup showing wave probe locations

time series of water surface elevation were measured

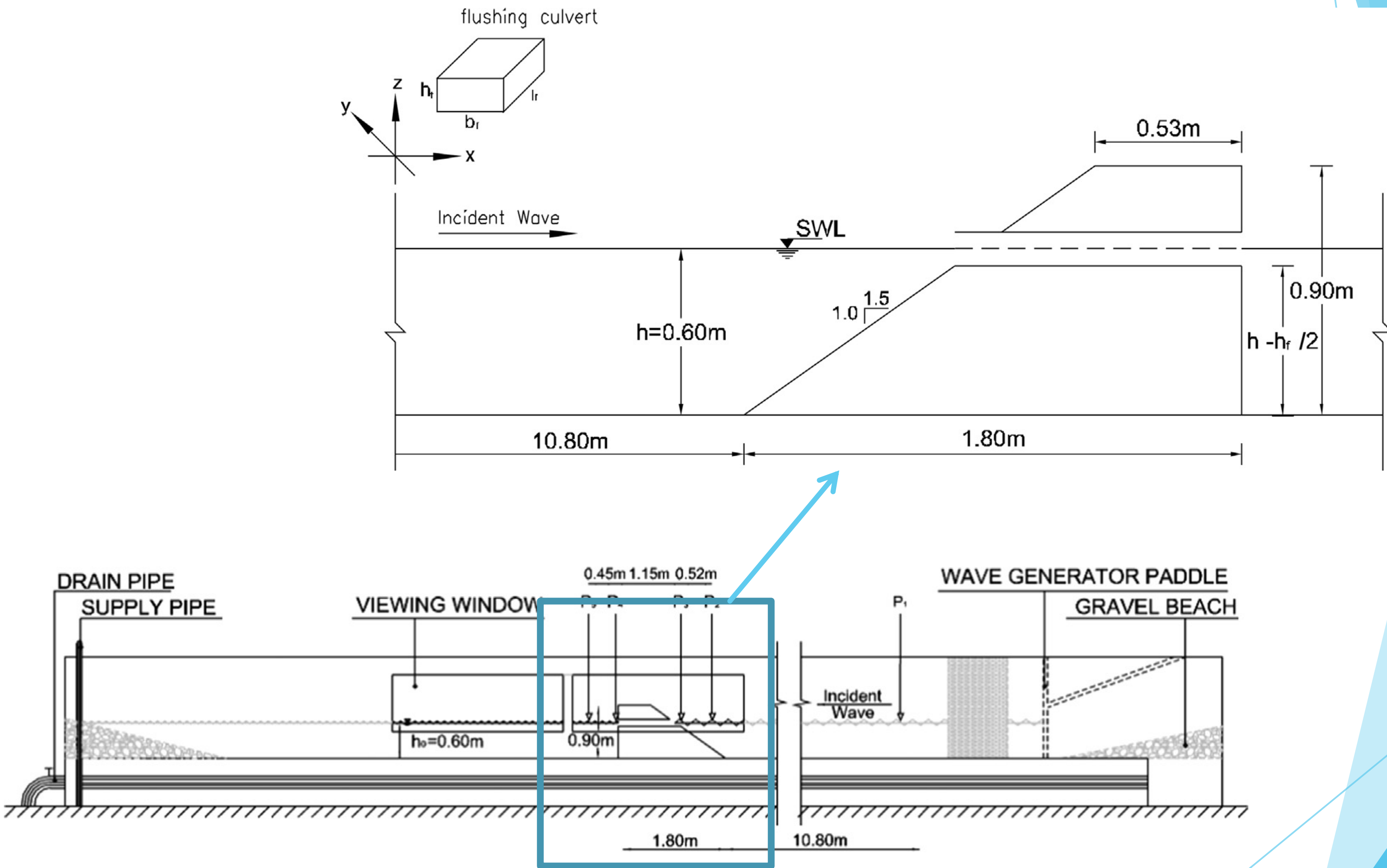
Experimental Data - 2D wave flume

The flushing culvert - with the center of their axes at the SWL:

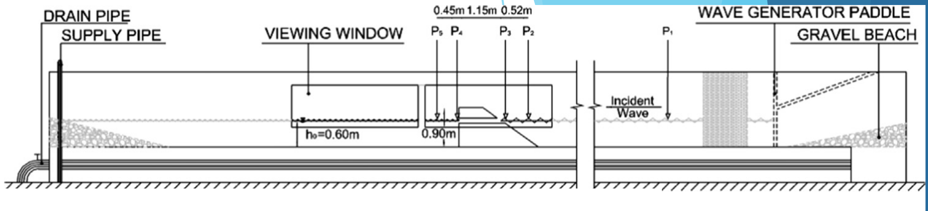
Case	h	l	b
	cm	cm	cm
A	12	50	18
B	12	50	24

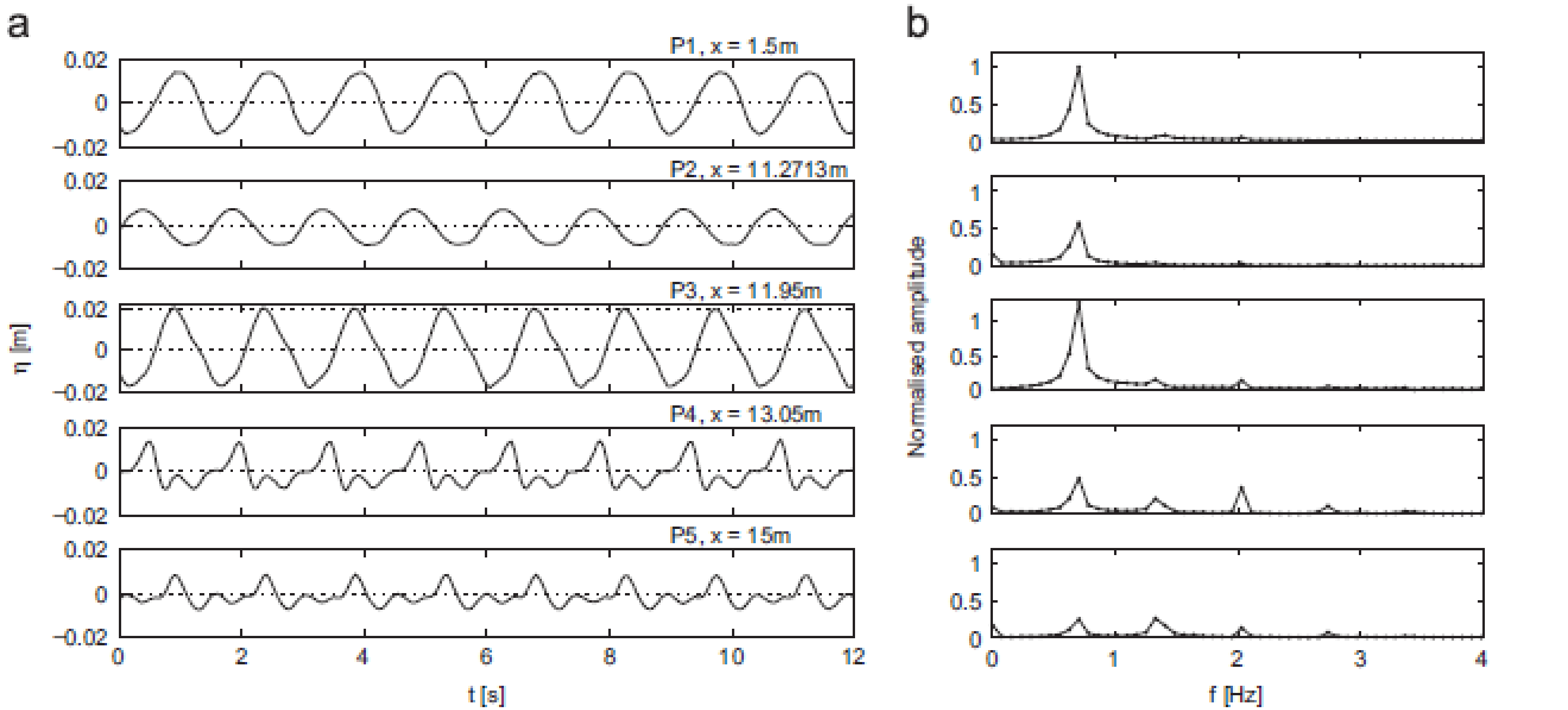
The measurements were performed for:

- 15 different incident regular waves
- 3 different periods [T= 1.48s 1.10s and 0.90 s]
- variation of the mean wave height ➔ $2 \leq H \leq 13$ cm

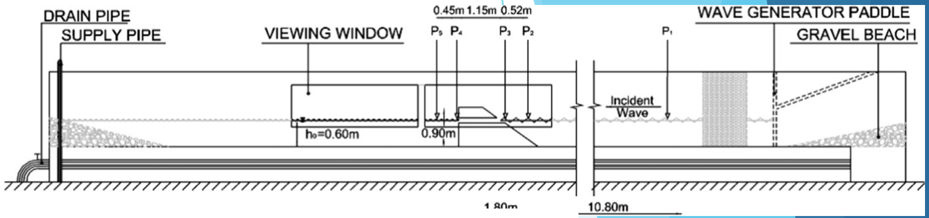

flushing culvert
z
y
x
h_f
b_f
l_f
Incident Wave
SWL
0.53m
1.5
1.0
h=0.60m
0.90m
h -h_f /2
10.80m
1.80m
DRAIN PIPE
SUPPLY PIPE
VIEWING WINDOW
0.45m 1.15m 0.52m
WAVE GENERATOR PADDLE
GRAVEL BEACH
P_1
Incident
Wave
h_0=0.60m
0.90m
1.80m
10.80m

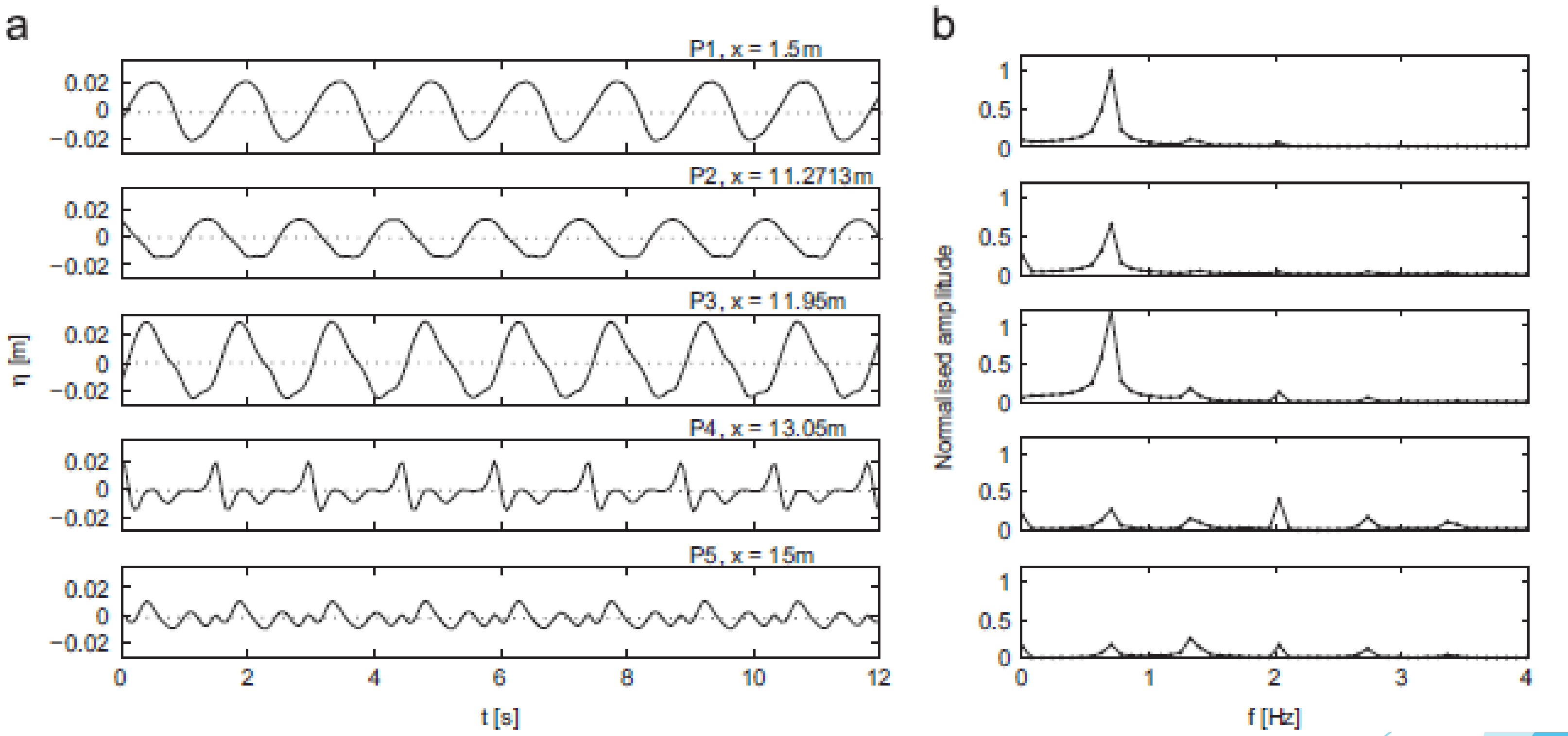
Case 7: T=1.47s, H=0.028 m, hf=0.18m, bf=0.24 m



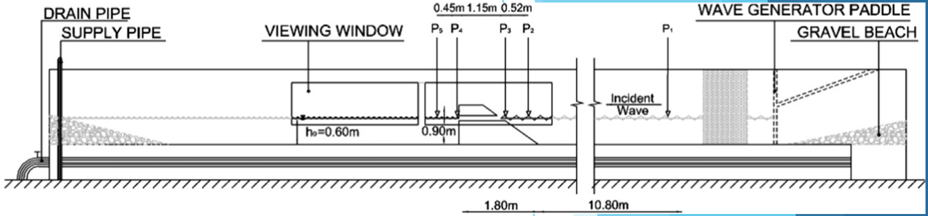


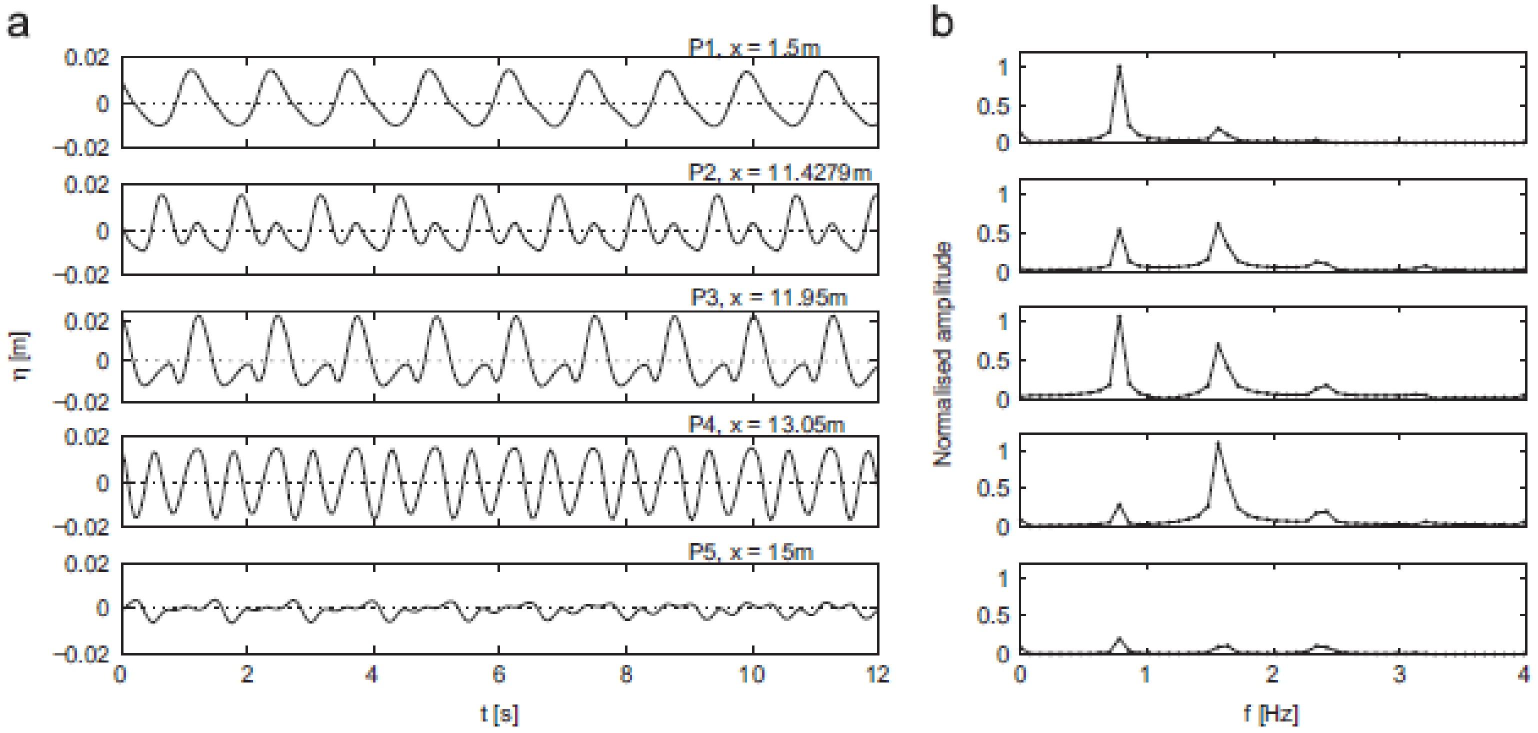
Case 7: T=1.47s, H=0.043m, hf=0.18m, bf=0.24 m



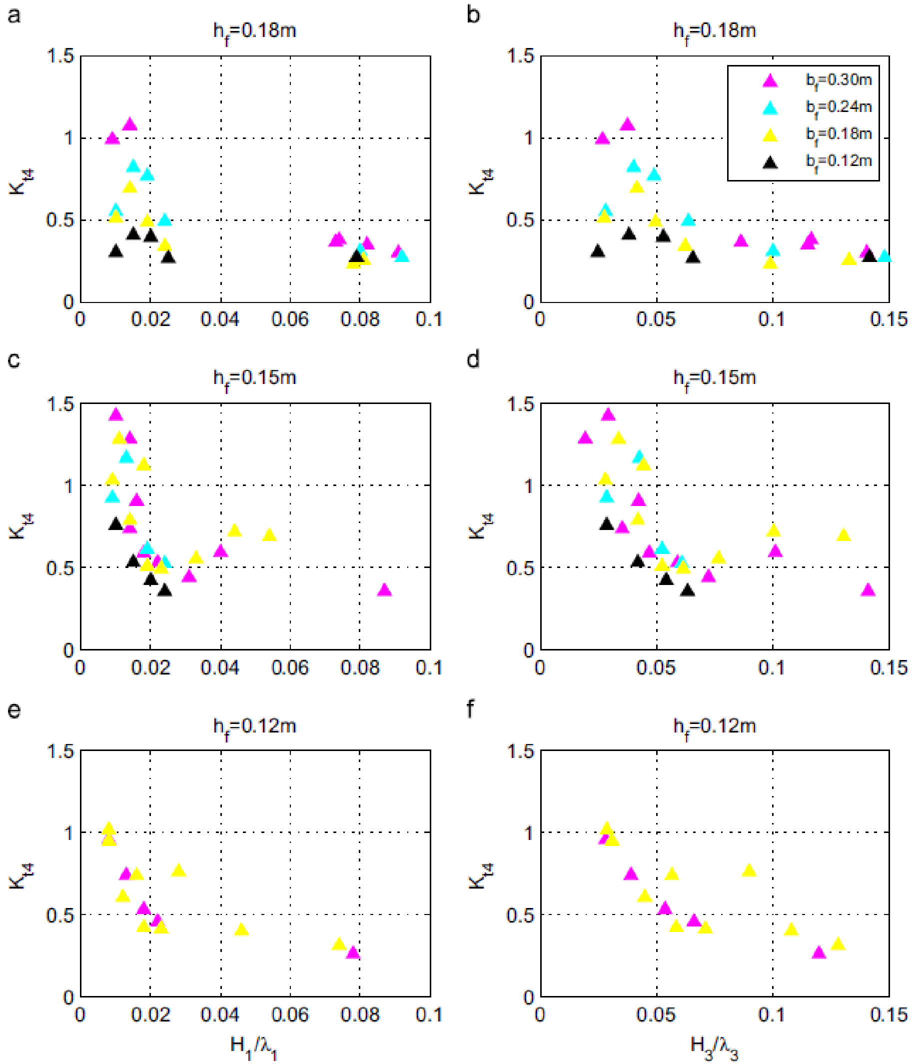


Case 7: T=1.26s, H=0.025m, hf=0.15m, bf=0.18 m

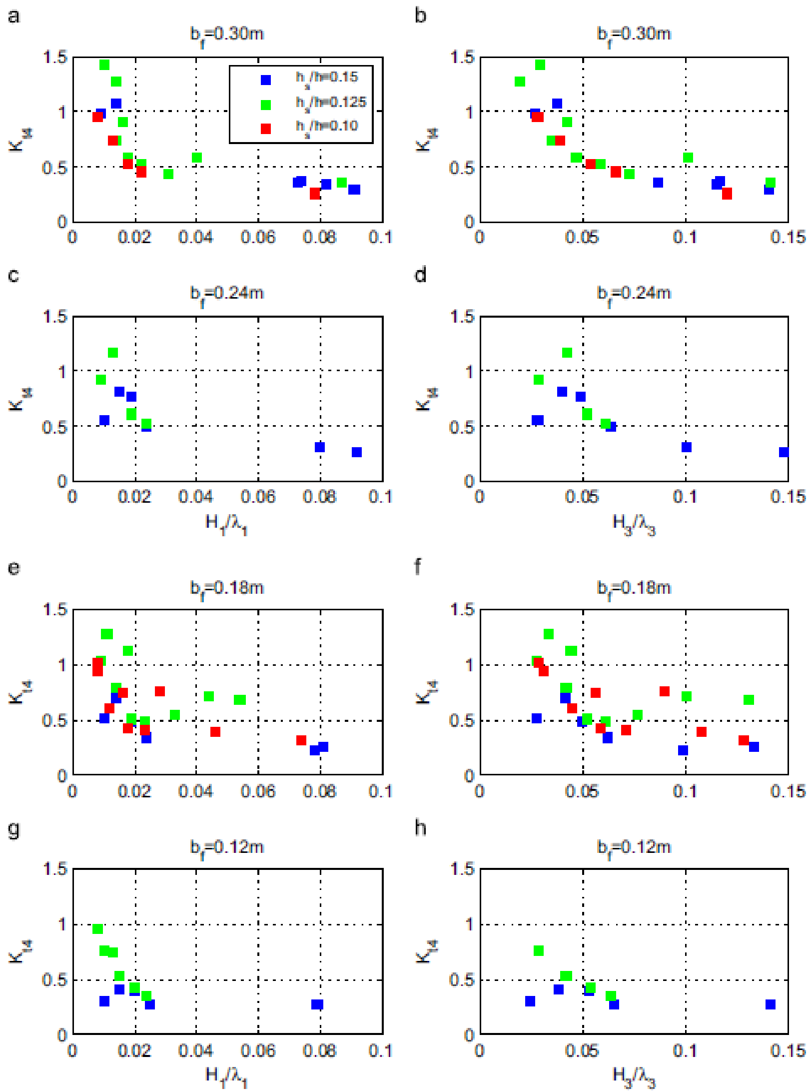




Transmission Coefficient



Transmission Coefficient



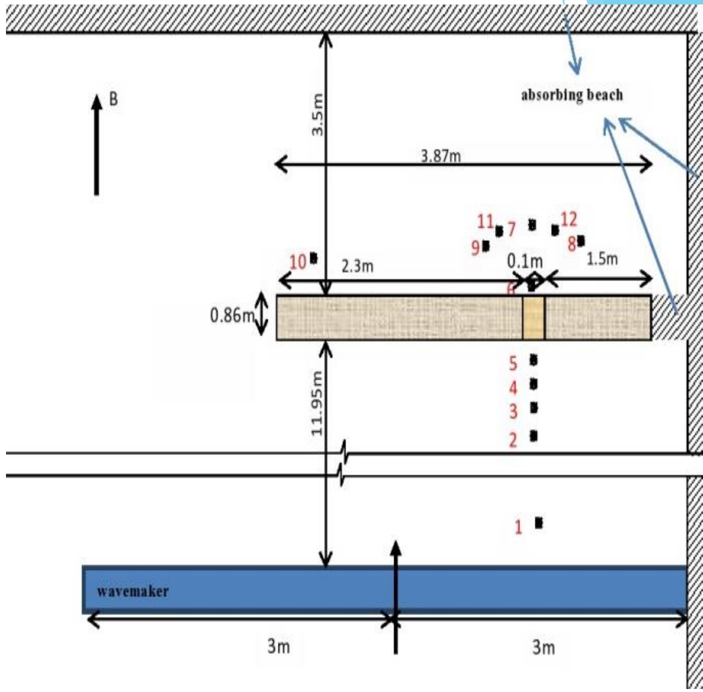
Experimental Data - 3D wave basin

The 3D wave basin:
- 26.80 m × 24.30 m
- 1.00 m depth

The physical model:
- 0.86 m width
- 0.225 m height
- 3.87 m length

Flushing culvert's dimensions in the 3D basin:

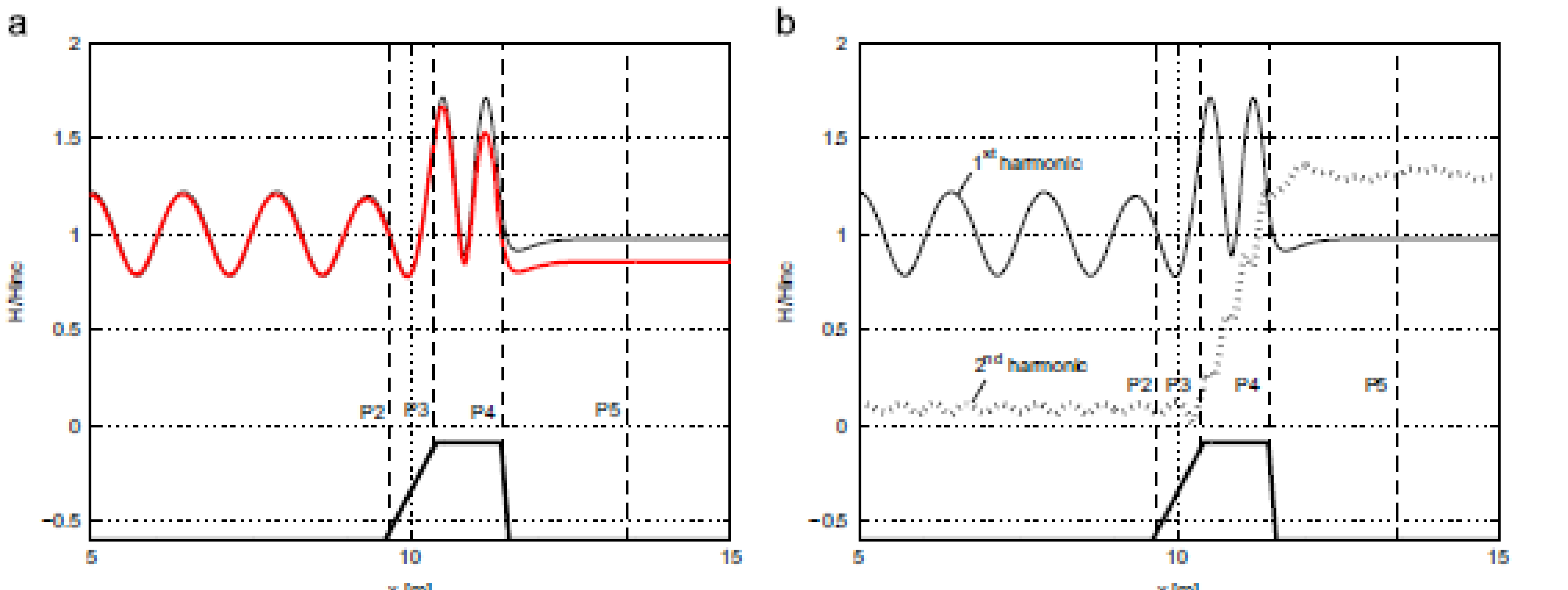
Case	h	l	b
	cm	cm	cm
1	10	86	10
2	10	86	8.5



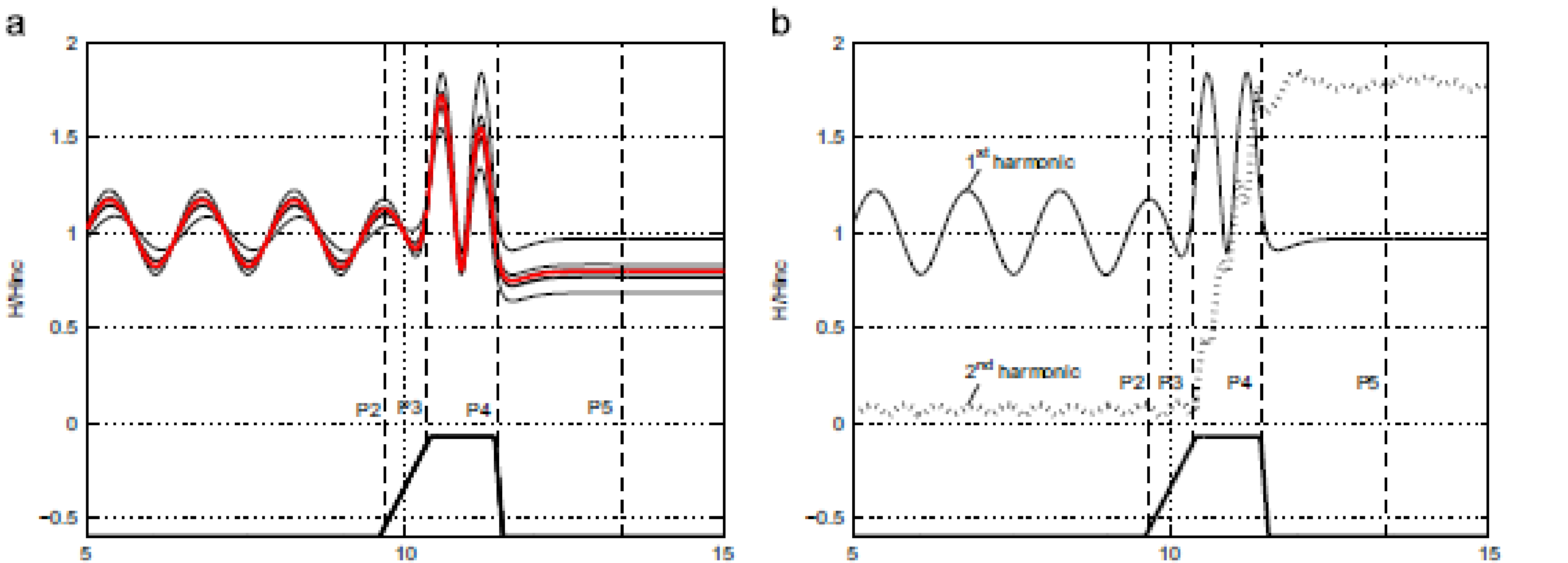
Sketch of the basin's plan view and the experimental set-up showing the 12 wave-probe locations

The measurements were performed for: 6 different incident regular waves - 2 wave periods [T= 0.60s and 0.75s] - variation of the mean wave height was $1.5 \leq H \leq 3.8$ cm

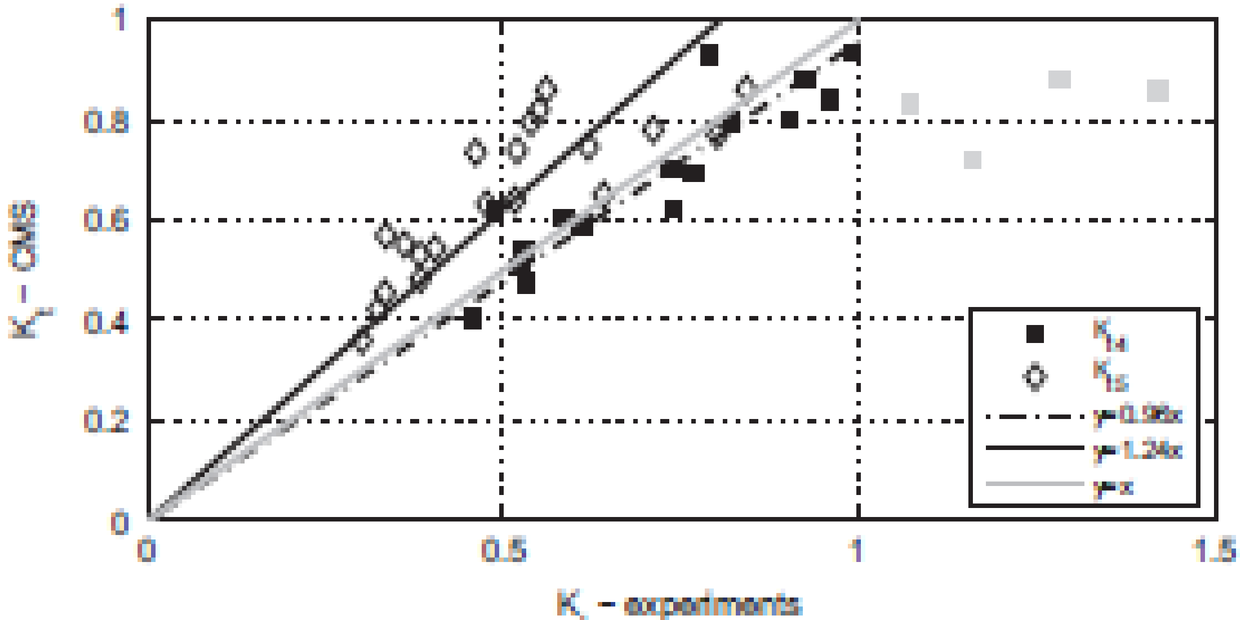
CMS calculations
T=1.47s, H=0.027m, hf=0.18m



CMS calculations
T=1.47s, H=0.027m, hf=0.15m



CMS-Experiments



Thank you for your attention..!