ICCE 2018
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The State of the Art and Science of Coastal Engineering

# RELIABILITY OF PRESSURE SENSORS TO MEASURE WAVE HEIGHT IN THE SHOALING REGION

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# MOTIVATION OF THE WORK

## RELIABILITY OF PRESSURE SENSORS TO MEASURE WAVE HEIGHT IN THE SHOALING REGION

## PROBLEM DESCRIPTION

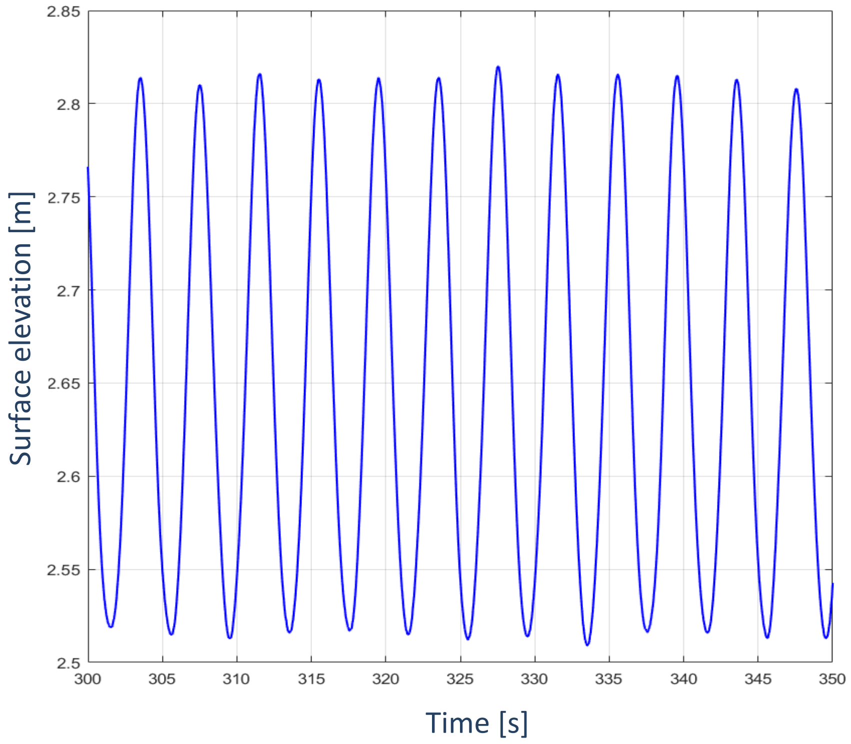
Pressure sensor is a very common used instrument to measure wave height in both laboratory and field investigations.

**PROS**

1. Robust
2. Inexpensive
3. Simple to use and calibrate
4. Do not need any surface support

**CONS**

1. Requires a compensation for depth attenuation
2. Transferring pressure records to wave elevation is still a nontrivial problem in shallow waters




**Surface elevation time series from pressure records (hydrostatic)**

# MOTIVATION OF THE WORK

## RELIABILITY OF PRESSURE SENSORS TO MEASURE WAVE HEIGHT IN THE SHOALING REGION

### GOALS OF THE WORK

- To assess the performance of a range of commonly used transfer functions to obtain wave height from pressure records by means of a large-scale lab dataset.

- To investigate different conditions as the wave travels in:
  - Intermediate waters
  - Shallow waters → Shoaling region; Surf zone

- To identify weaknesses of the transfer functions in order to develop a transfer function for shoaling region and surf zone.

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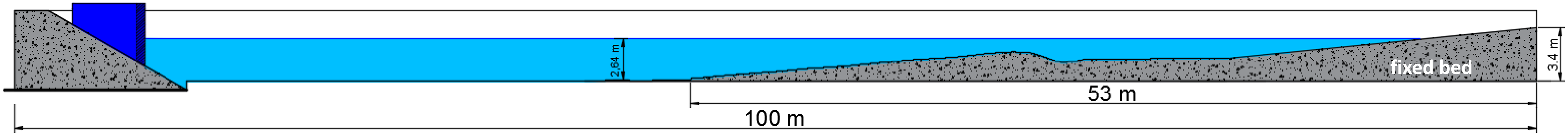
# EXPERIMENTAL SET-UP

## (CIEM - Canal de Investigació y Experimentació Marítima, Barcelona, SPAIN)




Flume longitudinal profile

Experimental flume (beach side)

| Test n. | H [m] | T [s] | Wave type |
|---|---|---|---|
| 1 | 0.4 | 4 | regular |
| 2 | 0.4 | 5 | regular |
| 3 | 0.4 | 6 | regular |
| 4 | 0.4 | 7 | regular |
| 6 | 0.5 | 4 | regular |
| 7 | 0.5 | 5 | regular |
| 9 | 0.6 | 3 | regular |
| 11 | 0.6 | 5 | regular |
| 12 | 0.7 | 3 | regular |
| 13 | 0.3 | 3 | regular |
| 14 | 0.2 | 4 | regular |
| 15 | 0.2 | 3 | regular |

Wave parameters

Flume experiment video

# EXPERIMENTAL SET-UP

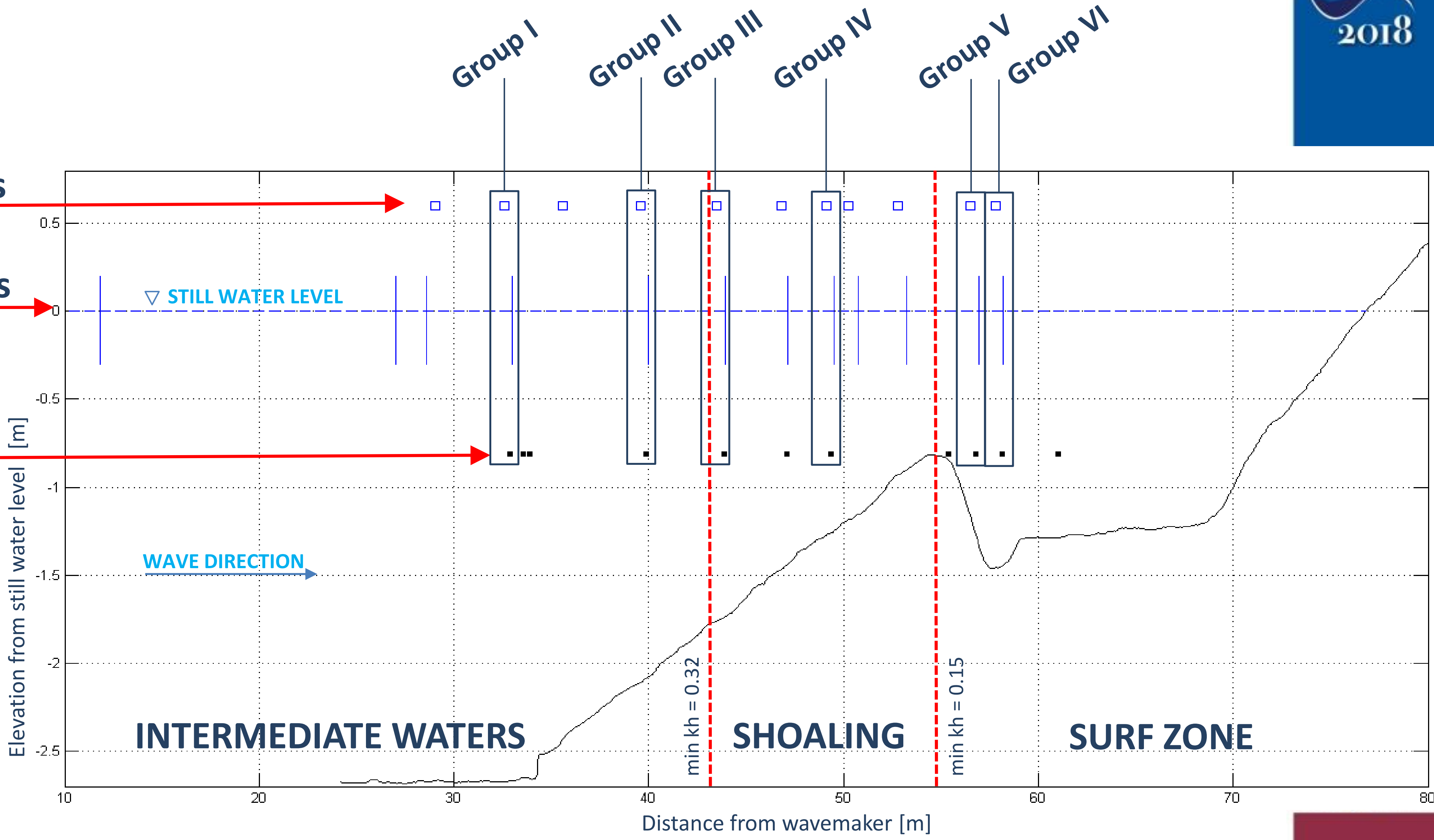
## FLUME LONGITUDINAL PROFILE AND GAUGES POSITIONING

Acoustic wave gauges

Resistive wave gauges

Pressure sensors

| Group | x [m] | Zone |
|---|---|---|
| I | 32.88 | Intermediate waters |
| II | 39.87 | |
| III | 43.85 | Shoaling |
| IV | 49.32 | |
| V | 56.81 | Surf zone |
| VI | 58.13 | |



# DATA ANALYSIS

## PRESSURE – WAVE ELEVATION TRANSFER FUNCTIONS

Four transfer functions are compared and assessed:

1. **Kuo & Chiu (CE, 1994) empirical transfer function**
2. **Neumeier (2003) linear wave theory depth attenuation correction**
3. **Oliveras *et al.* (SIAM J. Appl. Math. 2012) heuristic model**
4. **K. W. Inch (GT, 2014) linear wave theory depth attenuation correction**

A ranking based on deviation between $H_{e,tf}$ and $H_{e,wg}$ is carried out. **Five ranking classes are defined:**

$$D_{e,tf} = \left|1 - \frac{H_{e,tf}}{H_{e,wg}}\right|$$

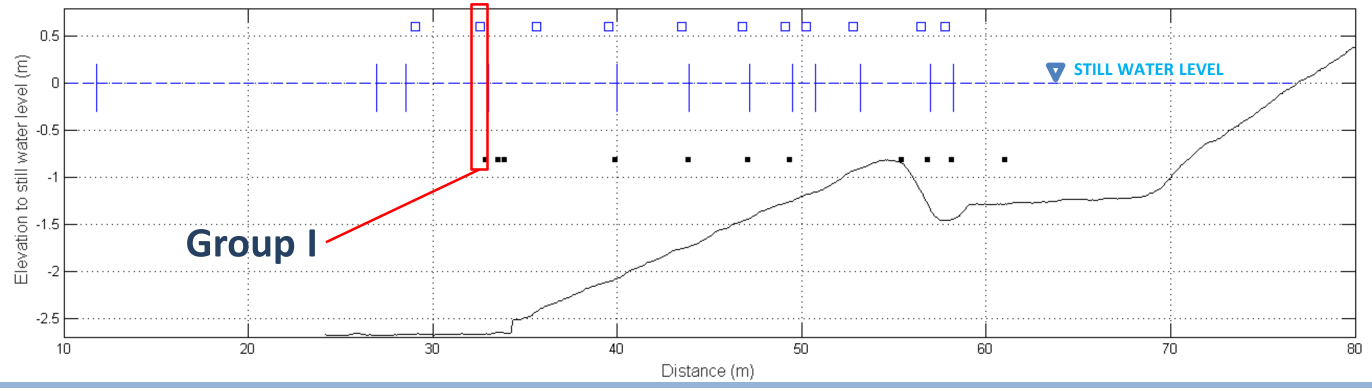
| Deviation ($D_{e,tf}$) | Ranking ($R_{e,tf}$) |
|---|---|
| $D_{e,tf} < 5\%$ | 1 |
| $5\% < D_{e,tf} < 10\%$ | 2 |
| $10\% < D_{e,tf} < 20\%$ | 3 |
| $20\% < D_{e,tf} < 30\%$ | 4 |
| $30\% < D_{e,tf}$ | 5 |

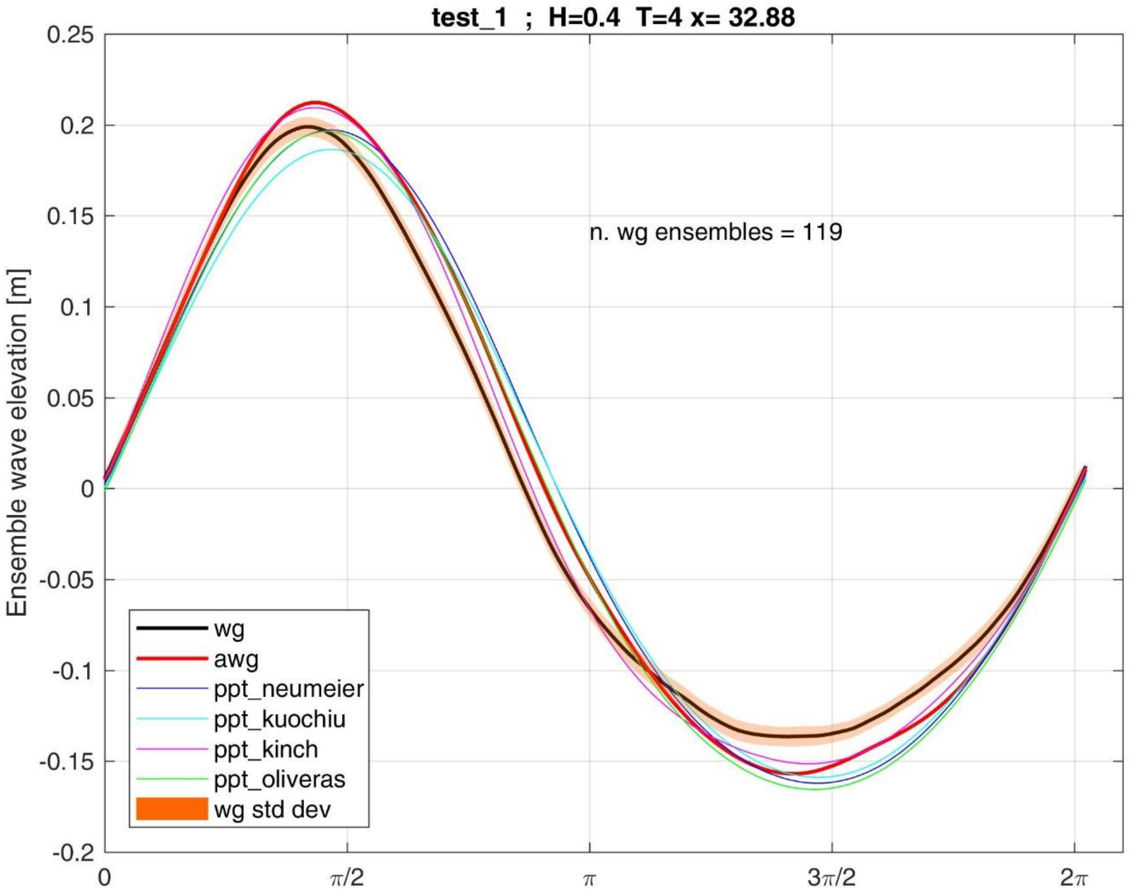
# DATA ANALYSIS

## ENSEMBLE AVERAGE WAVE HEIGHT

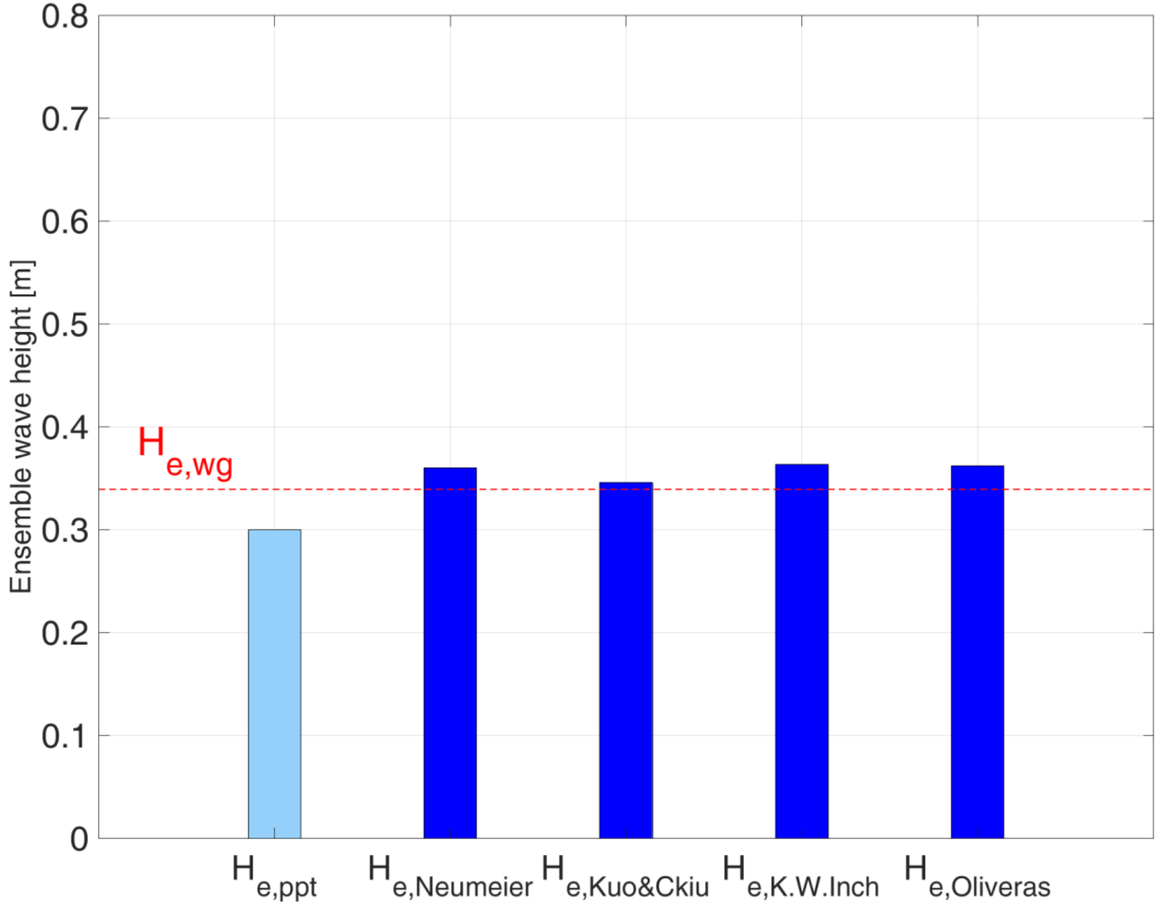
## INTERMEDIATE WATERS

**Test 12: H = 0.47 m T = 43 s**




Ensemble average



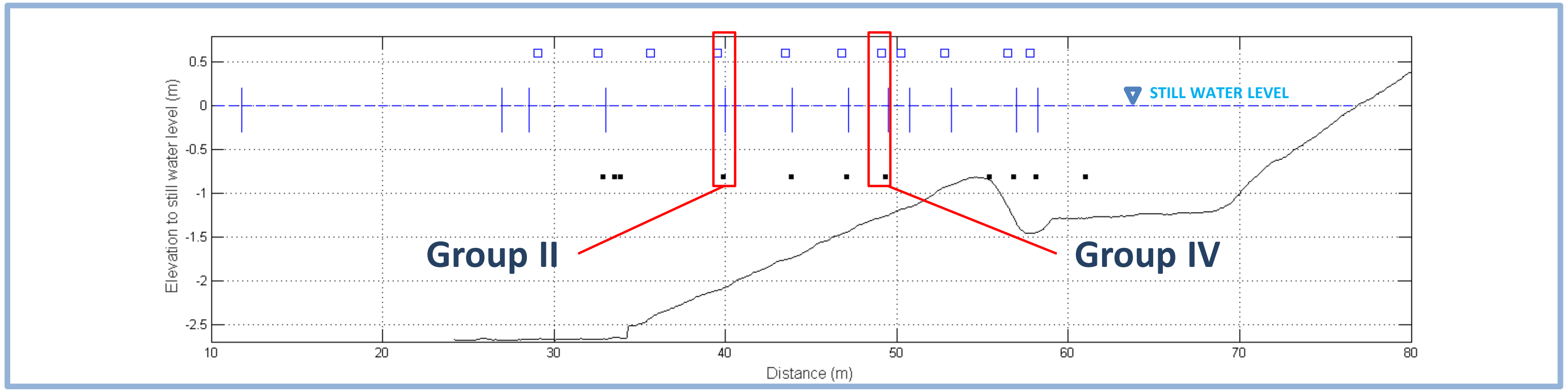

Ensemble average wave height comparison

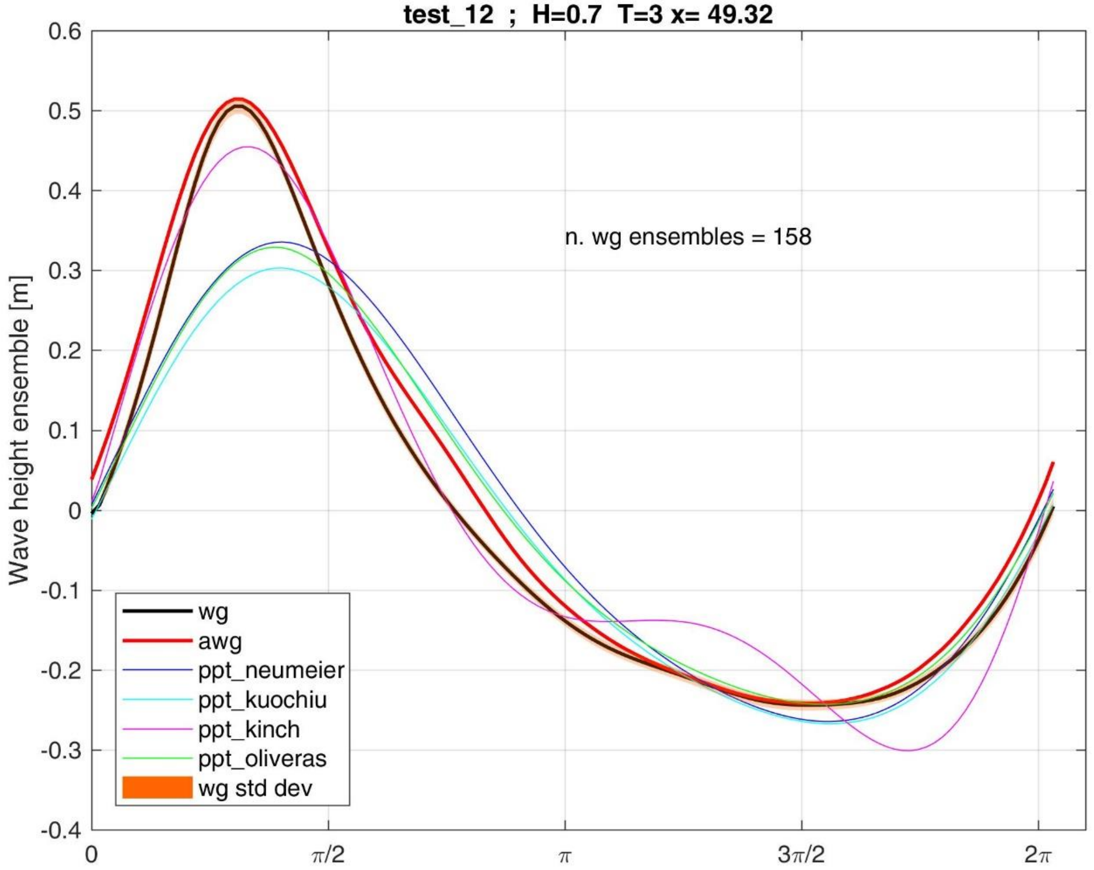
# DATA ANALYSIS

## ENSEMBLE AVERAGE WAVE HEIGHT

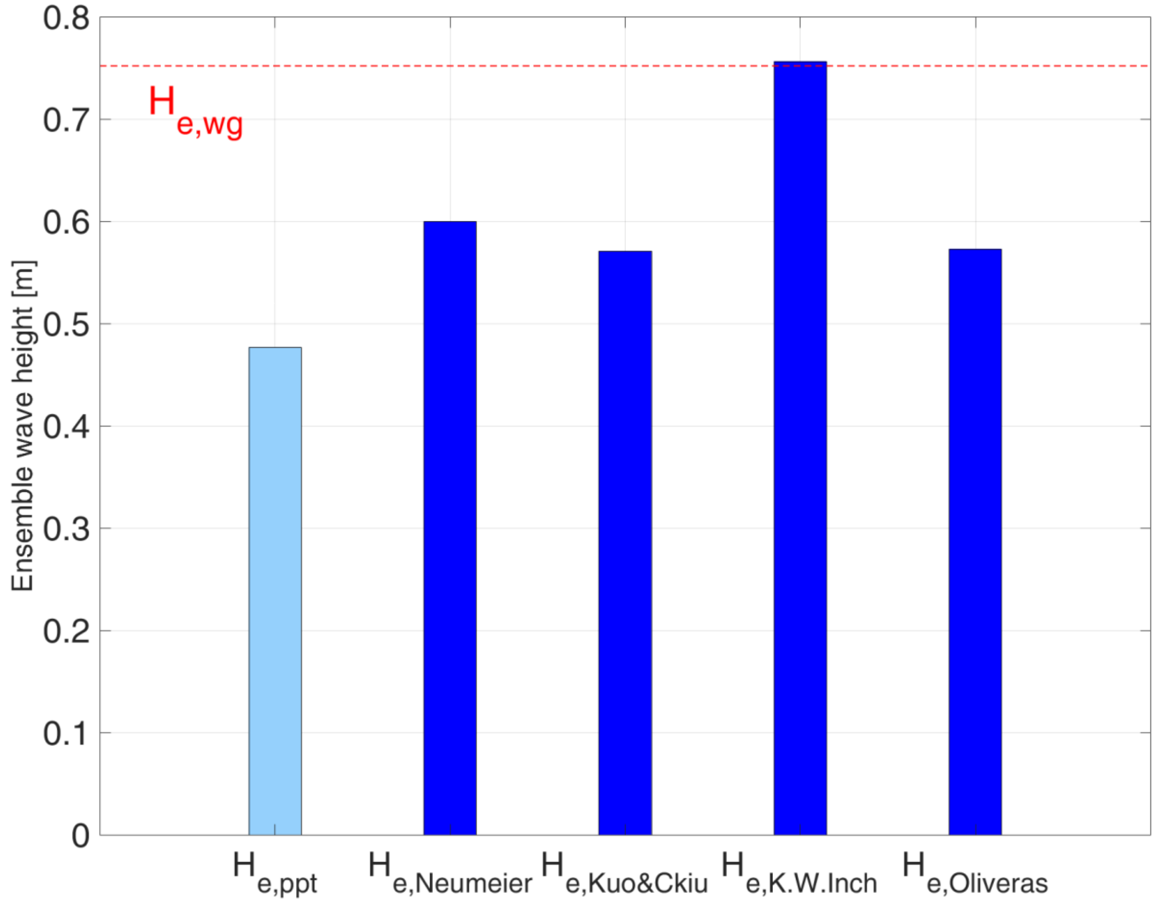
## SHOALING REGION

**Test 12:** H = 0.7 m T = 3 s




Ensemble average




Ensemble average wave height comparison

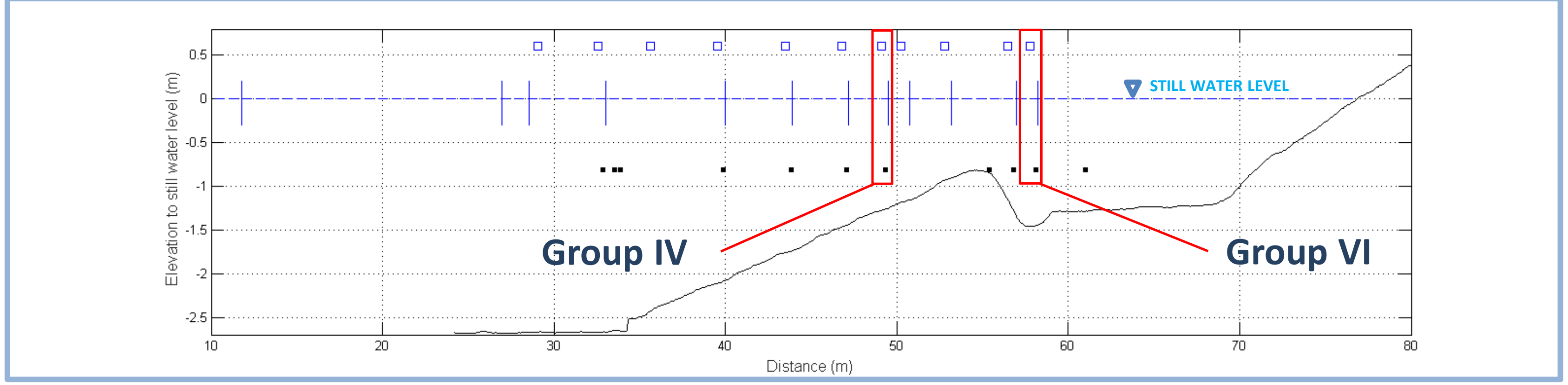
Ensemble average

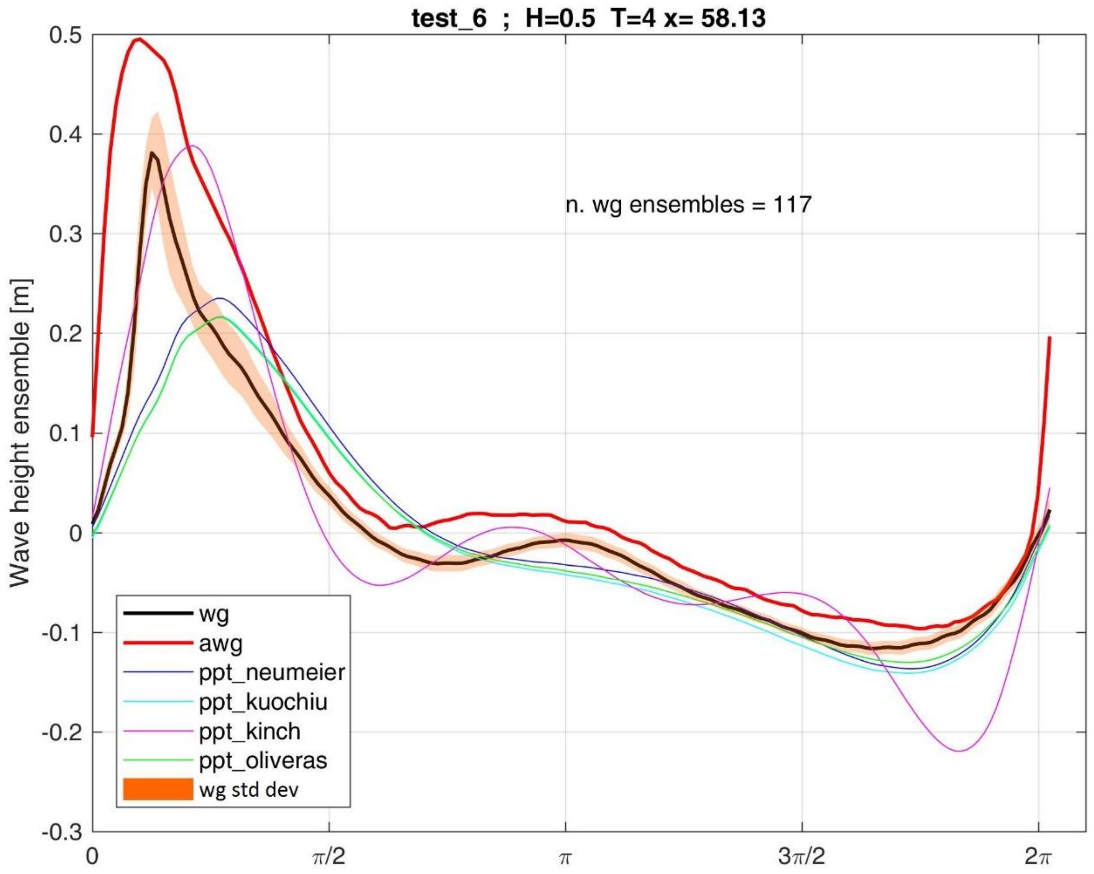
# DATA ANALYSIS

## ENSEMBLE AVERAGE WAVE HEIGHT

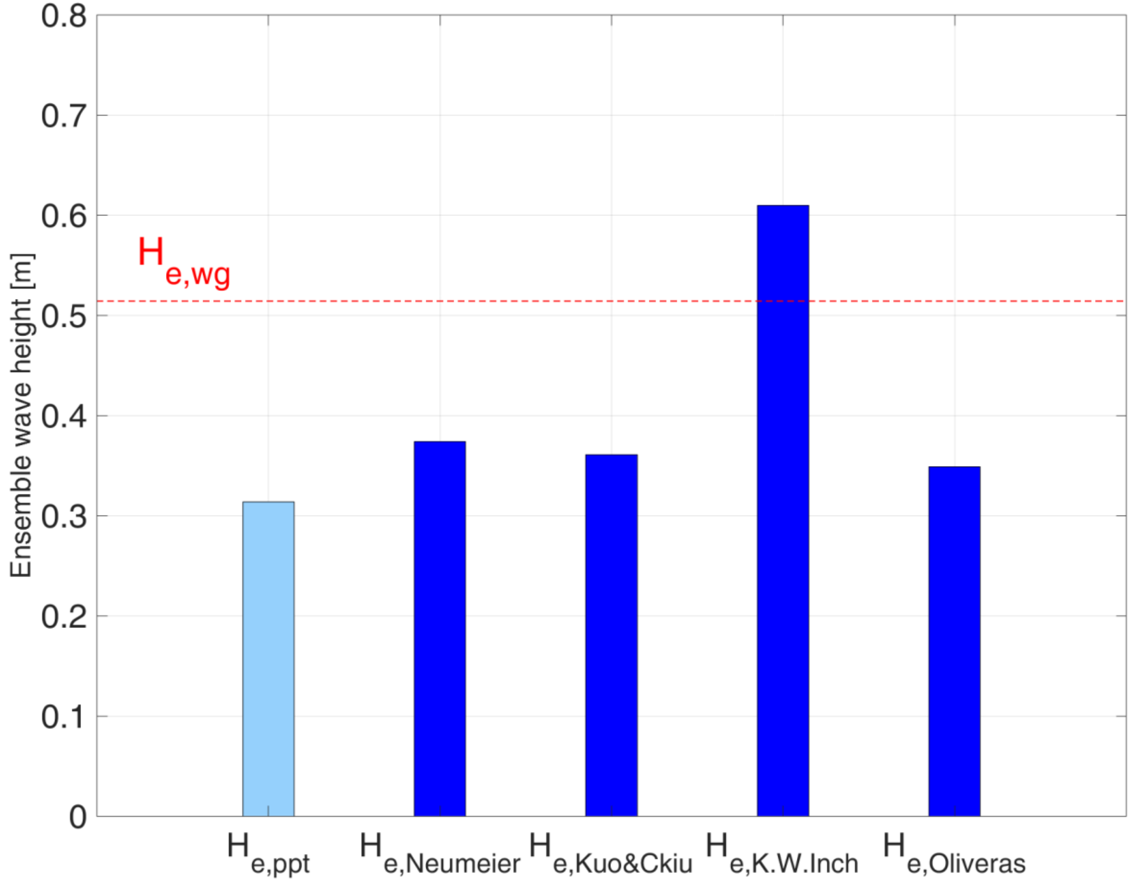
## SURF ZONE

**Test 6:** H = 0.5 m T = 4 s




Ensemble average




Ensemble average wave height comparison

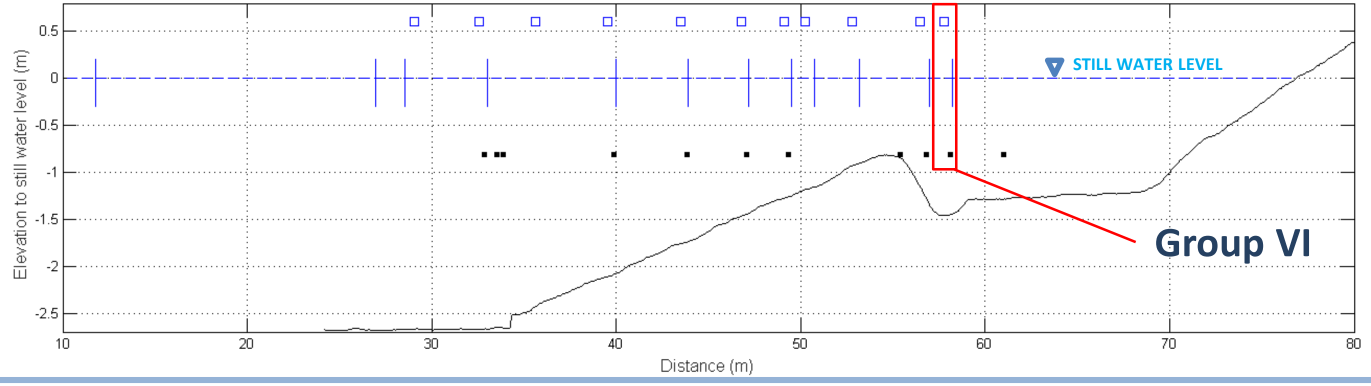
Ensemble average

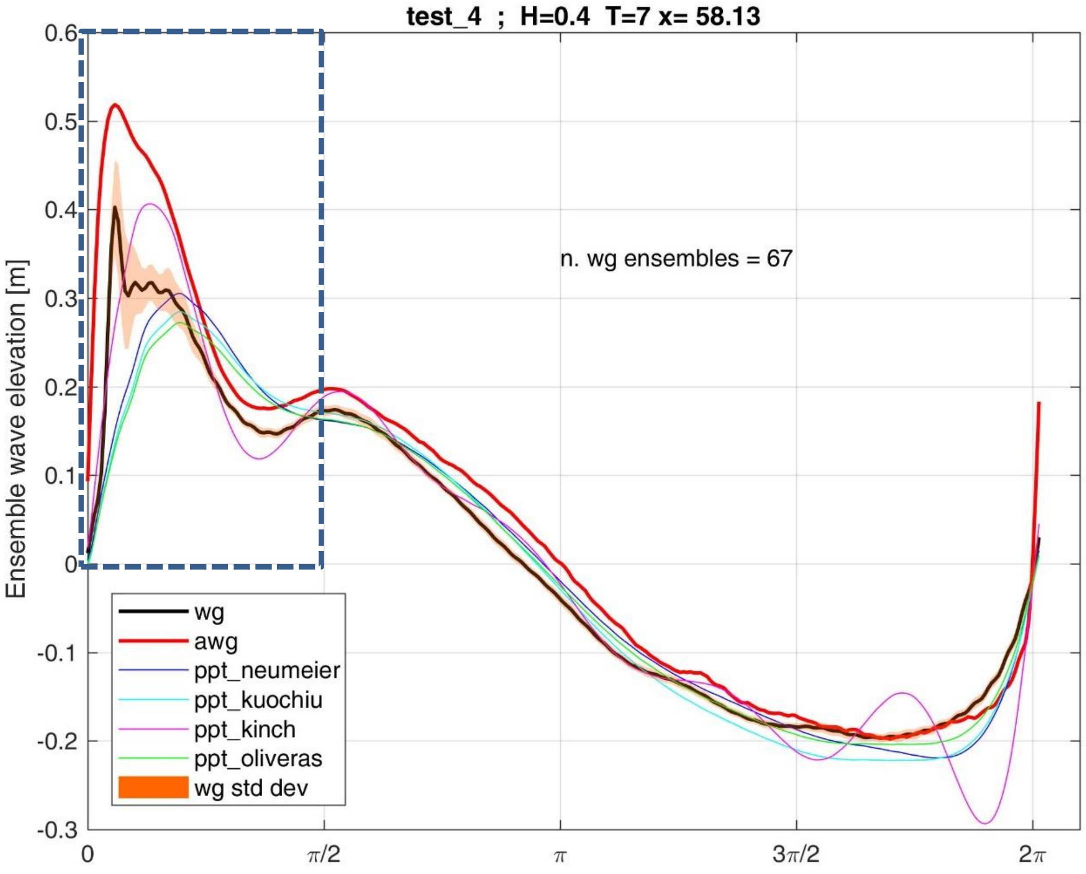
# DATA ANALYSIS

## ENSEMBLE AVERAGE WAVE HEIGHT

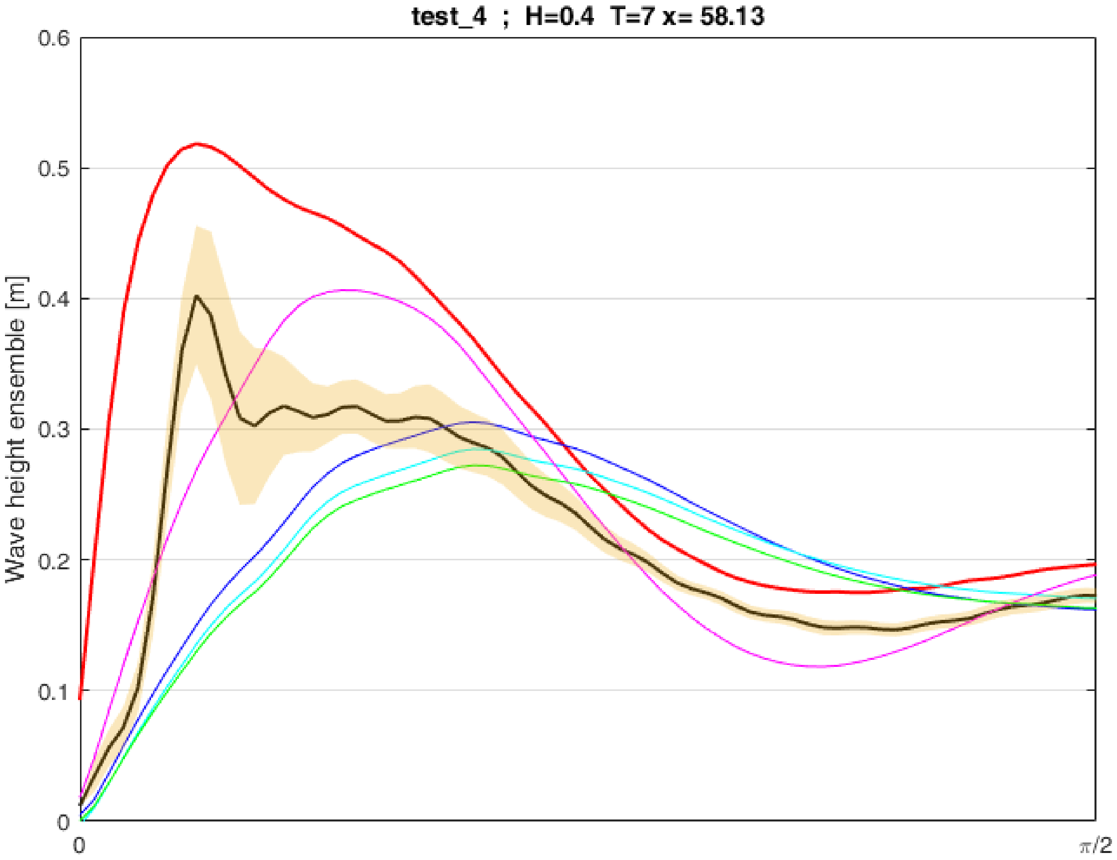
## SURF ZONE

**Test 4:** H = 0.4 m  T = 7 s



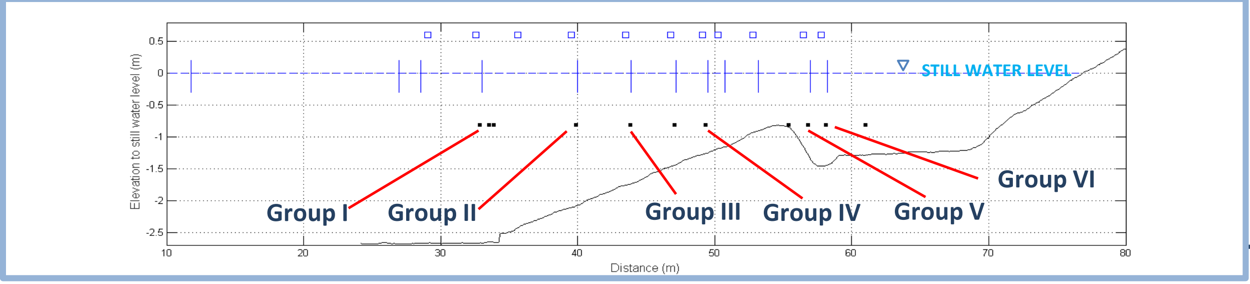

Ensemble average




Ensemble average (crest)

# RANKING CHART

## FROM ENSEMBLE AVERAGE WAVE HEIGHT




### SURF ZONE

**Deviation:**

$$D_{e,tf} = \left| 1 - \frac{H_{e,TF}}{H_{e,wg}} \right|$$

| Deviation ($D_{e,tf}$) | Ranking ($R_{e,tf}$) |
|---|---|
| $D_{e,tf} < 5\%$ | 1 |
| $5\% < D_{e,tf} < 10\%$ | 2 |
| $10\% < D_{e,tf} < 20\%$ | 3 |
| $20\% < D_{e,tf} < 30\%$ | 4 |
| $30\% < D_{e,tf}$ | 5 |

| | Group | $H_{wg}/L$ | $R_{e,Neumeier}$ | $R_{e,Kuo\ \&\ Chiu}$ | $R_{e,K.\ W.\ Inch}$ | $R_{e,Oliveras}$ |
|---|---|---|---|---|---|---|
| Test 14 | Group V | 0.0106 | 4 | 4 | 1 | 4 |
| Test 7 | | 0.0159 | 3 | 3 | 5 | 3 |
| Test 3 | | 0.0187 | 4 | 4 | 5 | 5 |
| Test 13 | | 0.0196 | 3 | 3 | 1 | 3 |
| Test 11 | | 0.0221 | 1 | 1 | 5 | 2 |
| Test 2 | | 0.0258 | 3 | 3 | 5 | 4 |
| Test 4 | | 0.0260 | 4 | 4 | 5 | 5 |
| Test 12 | | 0.0271 | 4 | 4 | 5 | 4 |
| Test 1 | | 0.0309 | 5 | 5 | 4 | 5 |
| Test 15 | | 0.0365 | 4 | 4 | 1 | 4 |
| Test 6 | | 0.0503 | 4 | 5 | 5 | 5 |
| Test 9 | | 0.0591 | 3 | 3 | 5 | 3 |
| Test 14 | Group VI | 0.0132 | 3 | 3 | 2 | 3 |
| Test 13 | | 0.0184 | 2 | 3 | 3 | 3 |
| Test 4 | | 0.0248 | 3 | 3 | 3 | 4 |
| Test 11 | | 0.0267 | 3 | 3 | 5 | 4 |
| Test 7 | | 0.0286 | 3 | 3 | 5 | 4 |
| Test 3 | | 0.0220 | 5 | 5 | 5 | 5 |
| Test 2 | | 0.0253 | 4 | 5 | 4 | 5 |
| Test 15 | | 0.0269 | 4 | 4 | 3 | 4 |
| Test 6 | | 0.0279 | 4 | 5 | 3 | 5 |
| Test 12 | | 0.0456 | 1 | 2 | 5 | 1 |
| Test 1 | | 0.0675 | 5 | 5 | 2 | 5 |
| Test 9 | | 0.0788 | 4 | 4 | 5 | 4 |

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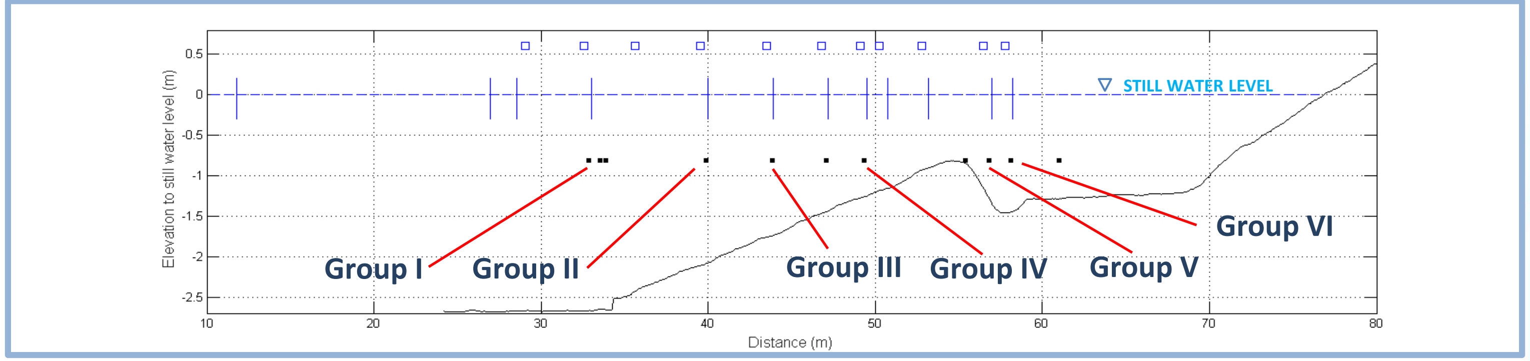
# DATA ANALYSIS

## ENSEMBLE AVERAGE WAVE HEIGHT VS STEEPNESS

### Transfer function: Kuo&Chiu




Wave steepness

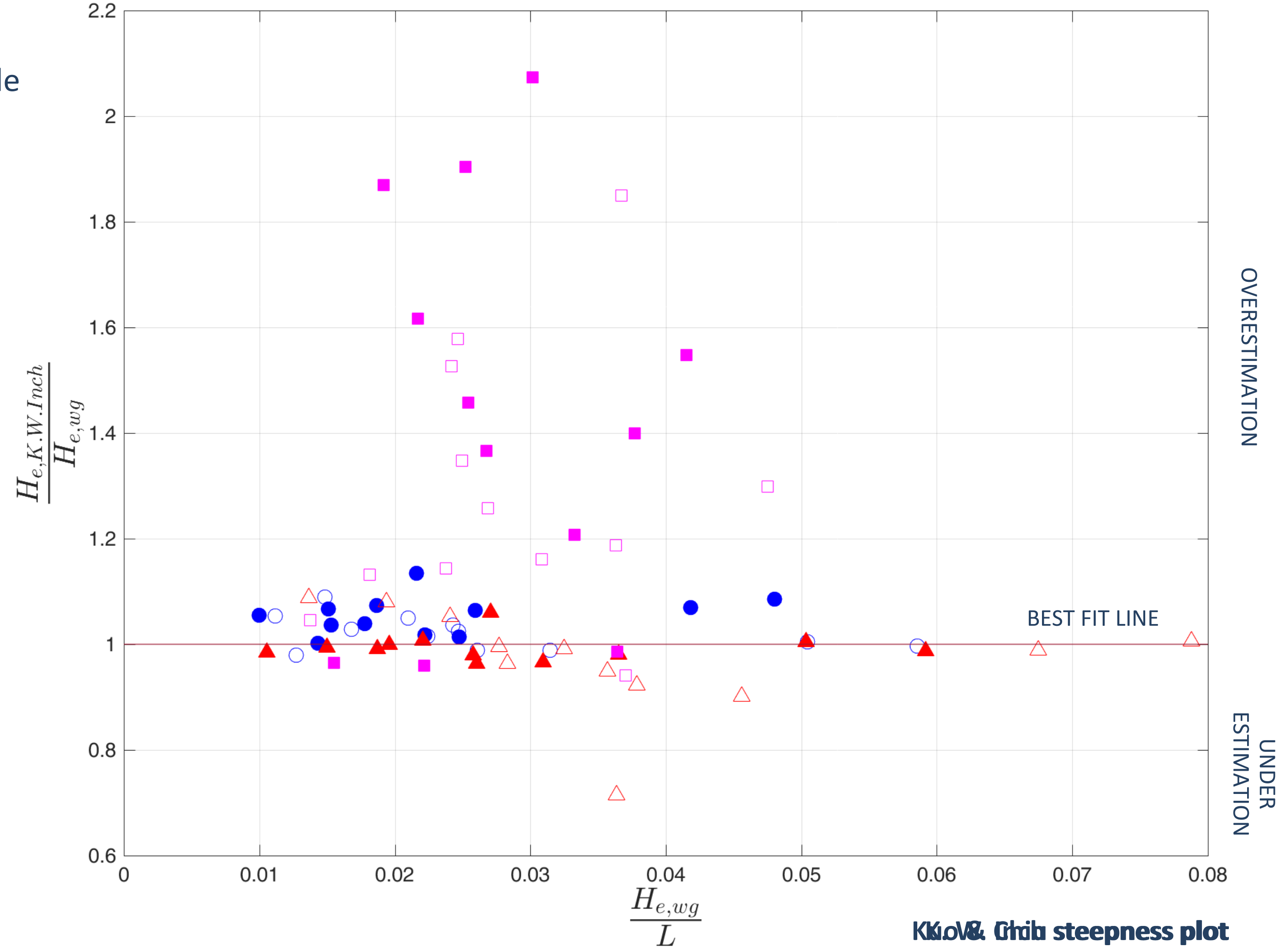
$$\frac{H_{e,wg}}{L}$$

VS

Ratio to wave gauges ensemble average wave height

$$\frac{H_{e,Kuo\&Chiu}}{H_{e,wg}}$$

| Group | x [m] | Marker | Condition |
|---|---|---|---|
| I | 32.88 | ● | Intermediate waters |
| II | 39.87 | ○ | |
| III | 43.85 | ▲ | Shoaling region |
| IV | 49.32 | △ | |
| V | 56.81 | ■ | Surf zone |
| VI | 58.13 | □ | |




**Kuo & Chiu steepness plot**

## WHAT NEXT?

# BOUSSINESQ-TYPE TRANSFER FUNCTION

## PRELIMINARY RESULTS

Transfer function derived from a fully nonlinear Boussinesq-type model for waves in the surf zone (Musumeci *et al.*, 2005).

$$\eta_{boussinesq,a} = \eta - \delta\mu^2 w^2 + \mu^2 \frac{\partial}{\partial t}\int_z^{\delta\eta} w dz + $$

$$+ \delta\mu^2 \frac{\partial}{\partial x}\int_z^{\delta\eta} uw dz - \mu^2 \frac{\partial}{\partial x}\int_z^{\delta\eta} \nu_t \frac{\partial u}{\partial z} dz$$


Ensemble average

# CONCLUSION

## RELIABILITY OF PRESSURE SENSORS TO MEASURE WAVE HEIGHT IN THE SHOALING REGION

- The accuracy of a range of commonly used transfer functions to obtain wave height from pressure records is assessed.
- The wave shape and height in the surf zone is not well recovered by none of the examined transfer functions.
- Data analysis highlighted a weakness in measuring wave height of resistive and acoustic gauges in the surf zone.
- Next step is the development of a more performant formula for pressure sensors in the surf zone.

| | | |
|---|---|---|
| **INTERMEDIATE WATERS** | Median Deviation: | $D_{e,Neumeier}$ = 3%<br>$D_{e,Kuo\&Chiu}$ = 4%<br>$D_{e,K.W.Inch}$ = 4%<br>$D_{e,Oliveras}$ = 5% |
| **SHOALING REGION** | Median Deviation: | $D_{e,Neumeier}$ = 11%<br>$D_{e,Kuo\&Chiu}$ = 11%<br>$D_{e,K.W.Inch}$ = 4%<br>$D_{e,Oliveras}$ = 14% |
| **SURF ZONE** | Median Deviation: | $D_{e,Neumeier}$ = 20%<br>$D_{e,Kuo\&Chiu}$ = 23%<br>$D_{e,K.W.Inch}$ = 32%<br>$D_{e,Oliveras}$ = 24% |

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DICAR

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