ICCE 2018

36TH INTERNATIONAL CONFERENCE ON COASTAL ENGINEERING 2018

Baltimore, Maryland | July 30 – August 3, 2018

The State of the Art and Science of Coastal Engineering

Numerical Modeling of non-breaking, impulsive breaking, and broken wave interaction with elevated structures: Laboratory validation and inter-model comparisons

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Motivation

- Complex wave and surge conditions due to hurricanes keep inducing damages on the built-environment.

- Need to improve current predictive force equations considering both surge and wave conditions.

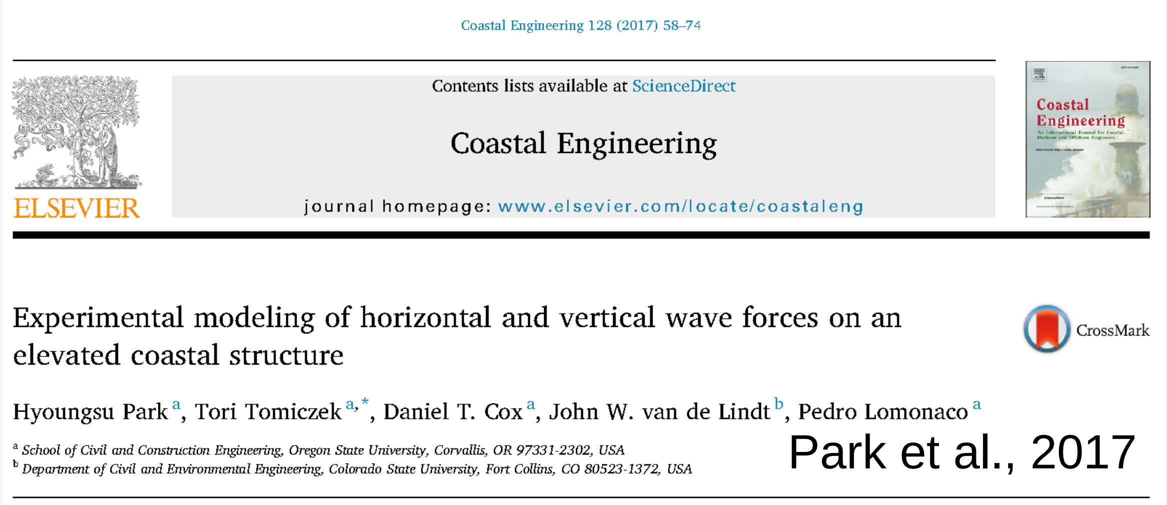
- Physical and numerical modeling studies could help to improve our understanding of wave induced force and pressure on the structures.

Bolivar Peninsula, TX (Hurricane Ike)

Objectives

- Validate two CFD models (IHFOAM and FLUENT) with the new experimental dataset (Park et al., 2017).
- Perform inter-model comparisons for the water surface deformation over the sloped beach, and pressures and forces at the elevated structure.
- Evaluate the sensitivity of CFD models for wave breaking conditions such as non-breaking, breaking (impulsive) and broken.

Physical model study


Coastal Engineering 128 (2017) 58–74

Contents lists available at ScienceDirect

Coastal Engineering

journal homepage: www.elsevier.com/locate/coastaleng

Experimental modeling of horizontal and vertical wave forces on an elevated coastal structure

Hyoungsu Park [a], Tori Tomiczek [a,*], Daniel T. Cox [a], John W. van de Lindt [b], Pedro Lomonaco [a]

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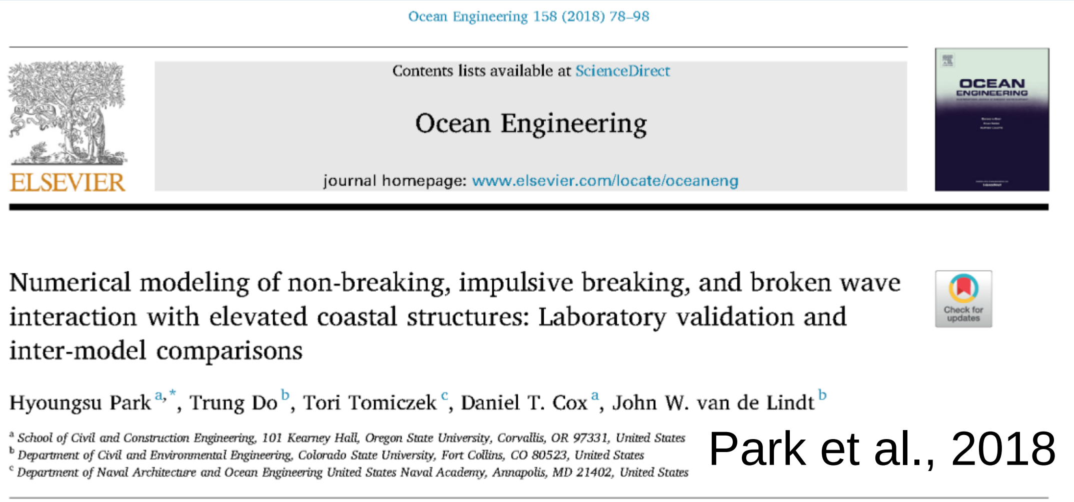
Park et al., 2017

Numerical model study


Ocean Engineering 158 (2018) 78–98

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Numerical modeling of non-breaking, impulsive breaking, and broken wave interaction with elevated coastal structures: Laboratory validation and inter-model comparisons

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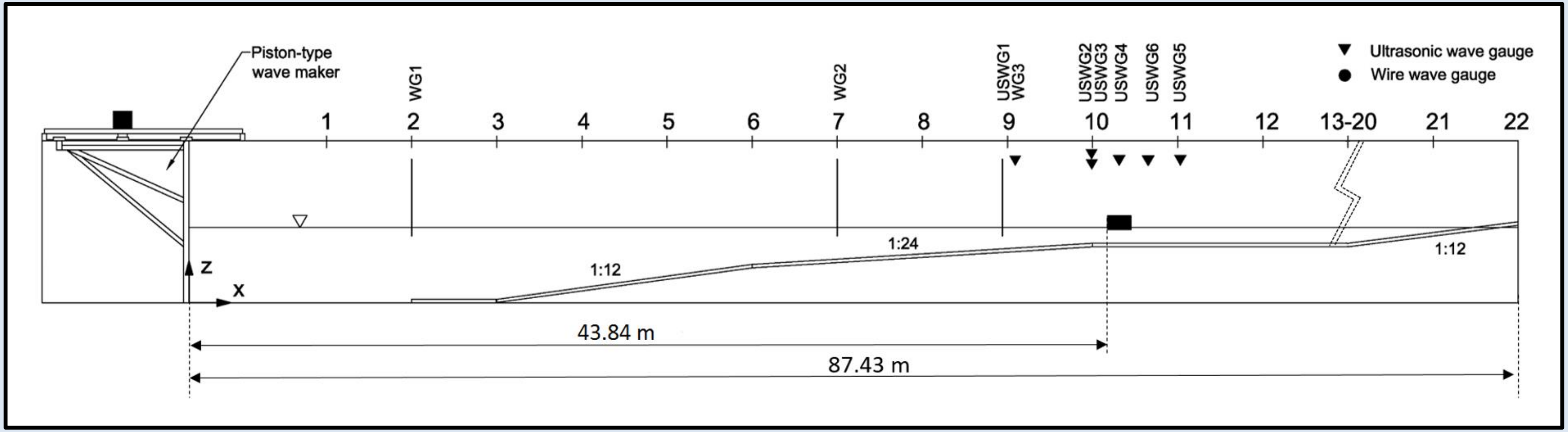
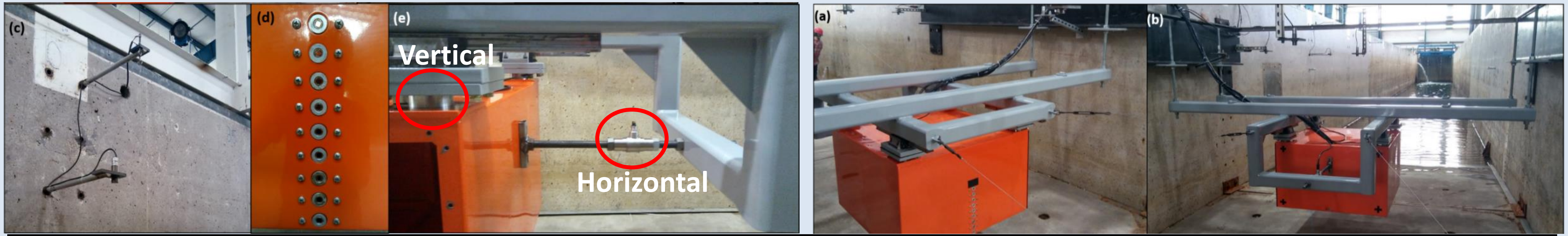
Park et al., 2018

Review of the physical model experiment (1/10 scale)

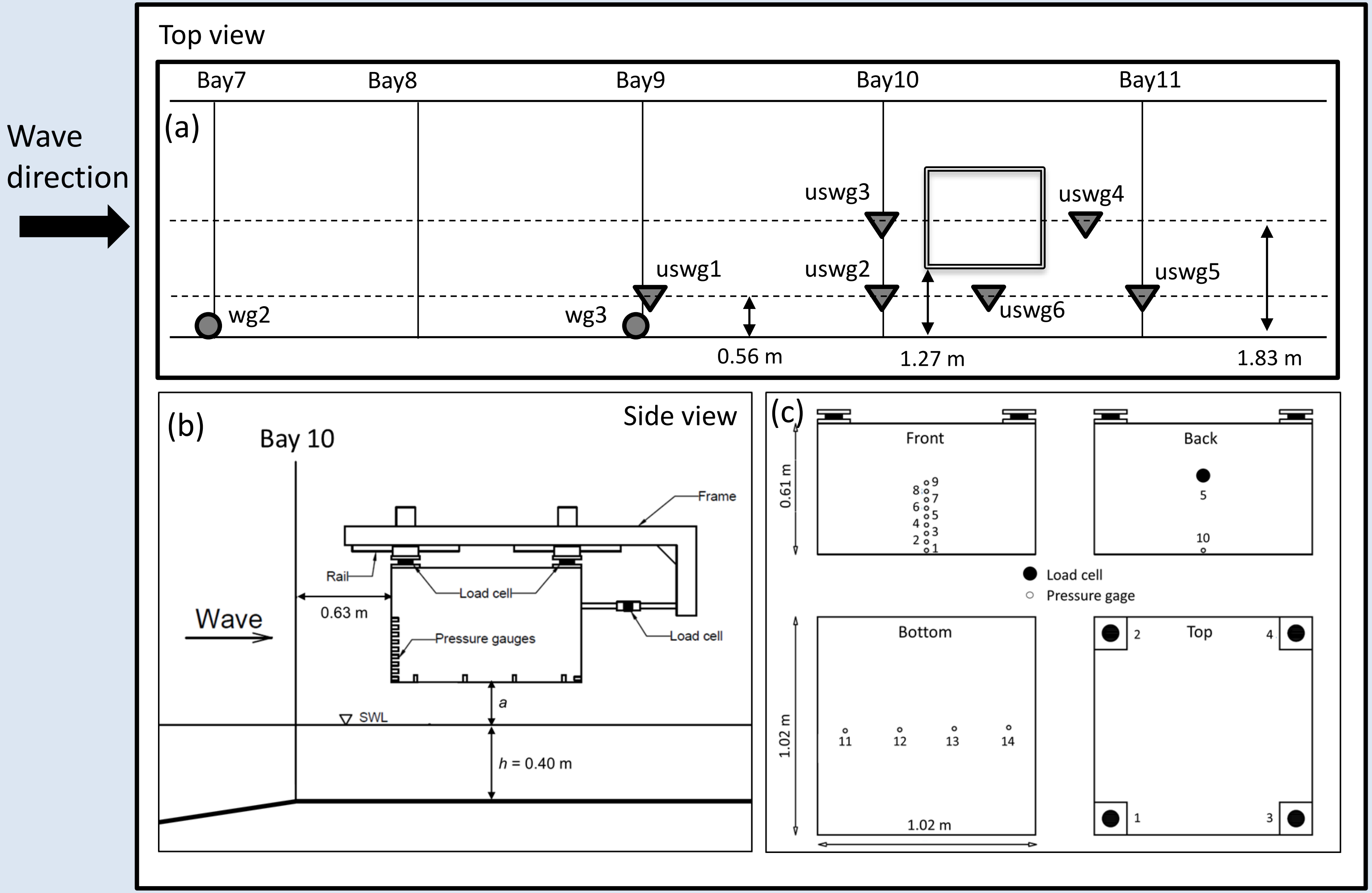
- Testbed: Bolivar Peninsula, TX, at Hurricane IKE.
- Performed at O.H Hinsdale wave lab. in Large Flume at OSU in 2016.





Wave gages | Pressure gages | load cells | Front specimen | Back specimen

Detail instruments setup near a specimen



1. Wave gages (9)

2. Pressure gages (14)
   - Front (9)
   - Back (1)
   - Bottom (4)

3. Load cells (5)
   - Horizontal (1)
   - Vertical (4)

Wave conditions for Physical models

Table 1
Experimental wave conditions.

Park et al., 2017

Exp.	TMA				REG				TRAN			
	$H_{1/3}$ (m)	T_P (s)	h (m)	Dur. (min)	$\overline{H}$ (m)	$\overline{T}$ (s)	h (m)	Dur. (min)	A (m)	T_R (s)	h (m)	t_s (s)
X1	0.10	3.72	2.15	40.0	0.10	4.10	2.15	4.00	0.51	36.4	2.00	10.0
X2	0.19	3.86	2.15	40.0	0.21	4.10	2.15	4.00	0.34	51.0	2.00	15.0
X3	0.29	4.10	2.15	40.0	0.29	4.10	2.15	4.00	0.28	87.2	2.00	20.0
X4	0.40	4.10	2.15	40.0	0.40	4.10	2.15	4.00	0.21	109	2.00	25.0
X5	0.50	3.86	2.15	40.0	0.50	4.10	2.15	4.00	0.18	117	2.00	30.0
X6	0.16	2.52	2.15	25.0	0.16	2.52	2.15	2.50	0.16	120	2.00	35.0
X7	0.21	2.98	2.15	30.0	0.23	2.98	2.15	3.00	0.14	154	2.00	40.0
X8	0.25	3.28	2.15	35.0	0.26	3.64	2.15	3.50	0.13	162	2.00	45.0
X9	0.34	4.68	2.15	45.0	0.35	4.68	2.15	4.50				
X10	0.39	5.04	2.15	50.0	0.42	5.04	2.15	5.00				

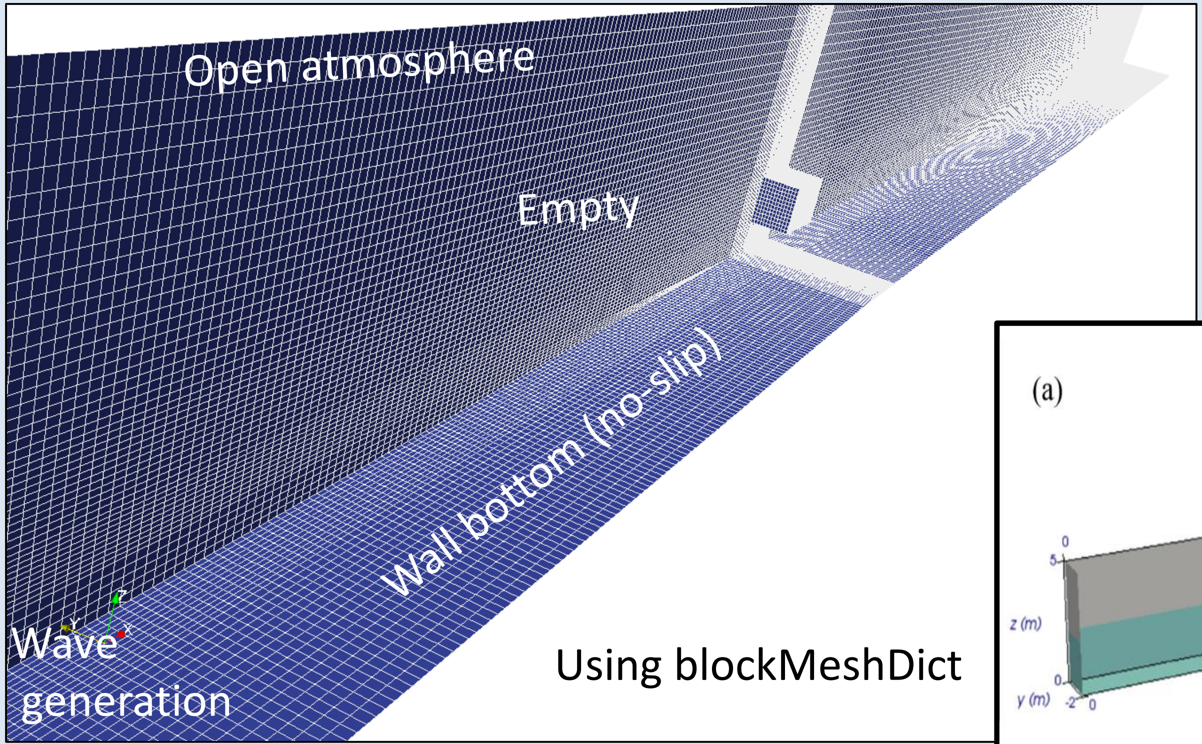
Three wave conditions for CFD model validation

Wave type at the specimen	Height, Period (REG)
Non-breaking (X2)	H=0.21m, T=4.10 s
Breaking (Impulsive) (X8)	H=0.26m, T=3.64 s
Broken (X4)	H=0.4m, T=4.10 s

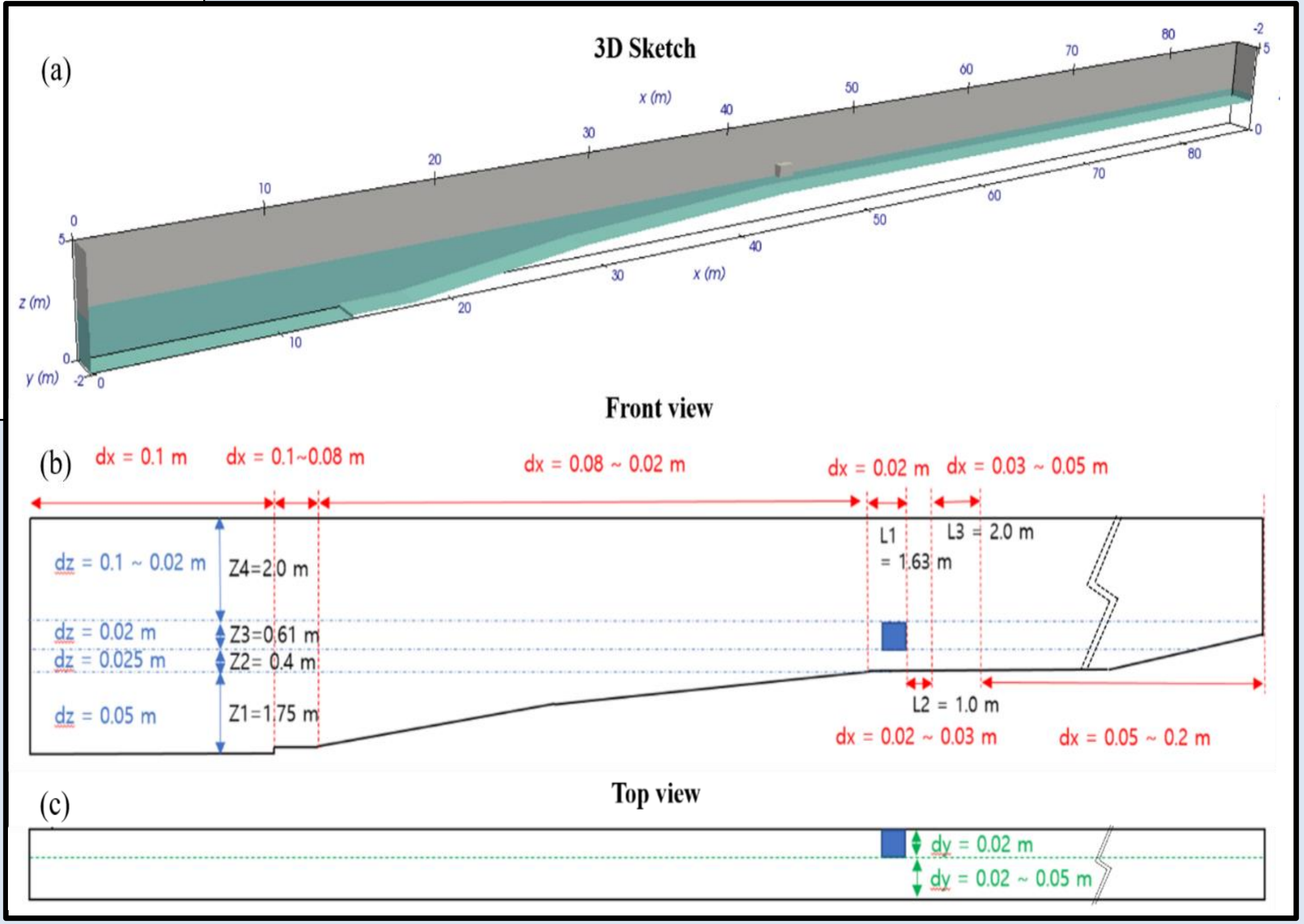
- Fixed sloped bathymetry
- Constant depth (h=2.15 m) and air gap (a = 0 m).

Physical model data are available from the presenter
Hyoungsu.Park@gmail.com

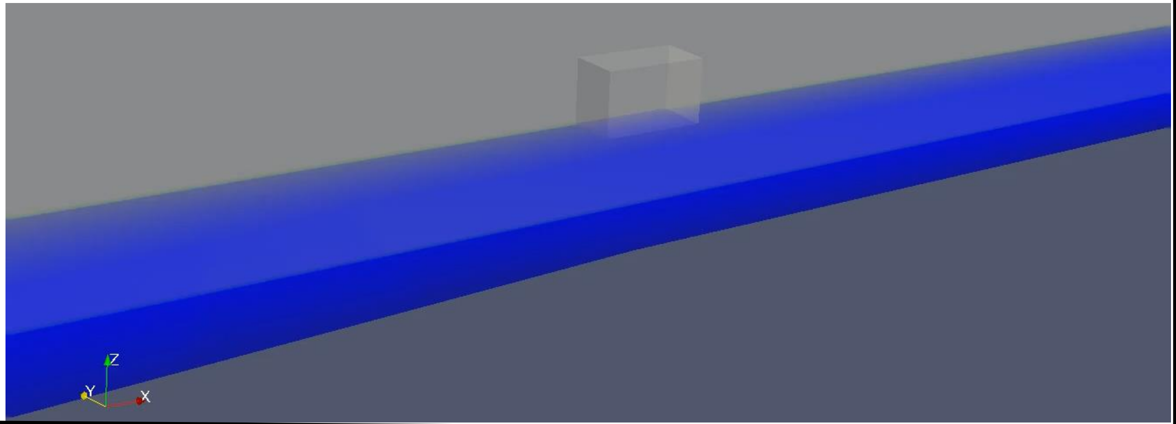
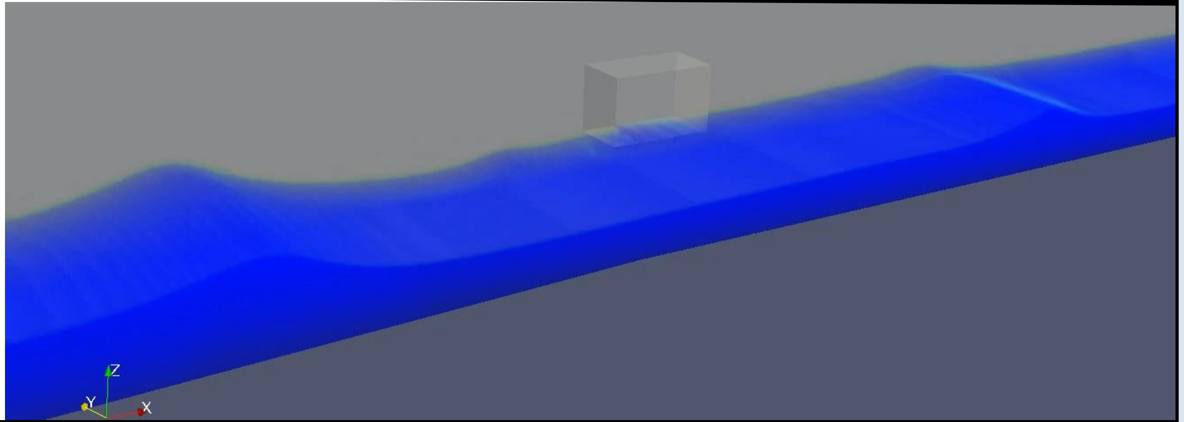
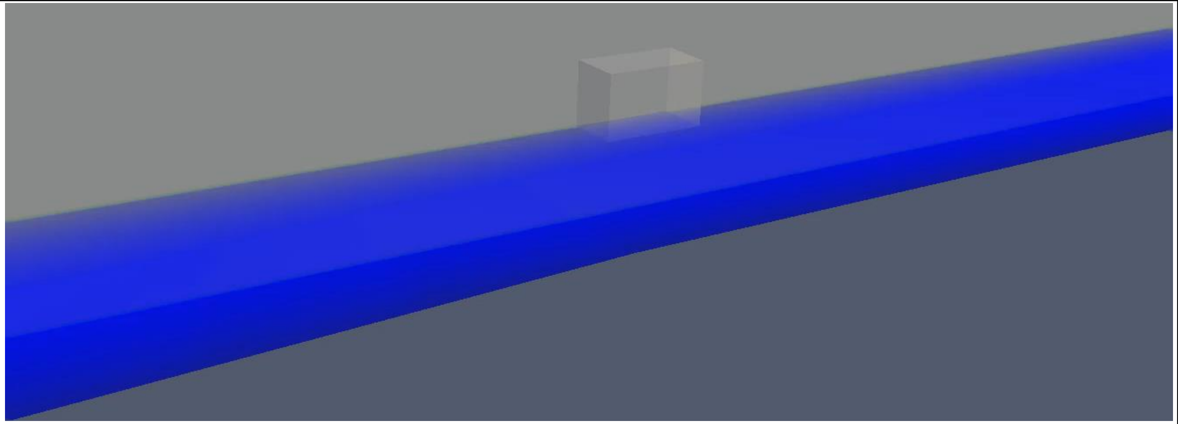
OpenFOAM (IHFOAM) setup



dx, dy, dz (m)	0.02 – 0.1
Number of elements	3.1 milion
Co	0.5

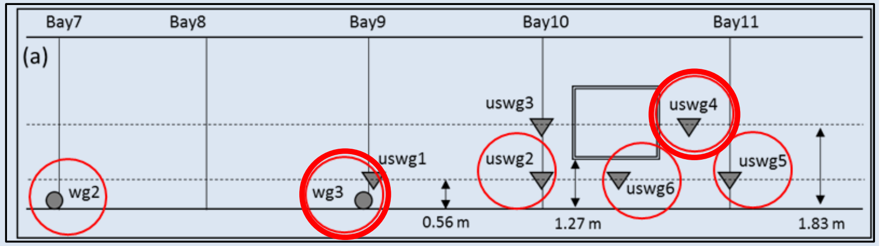


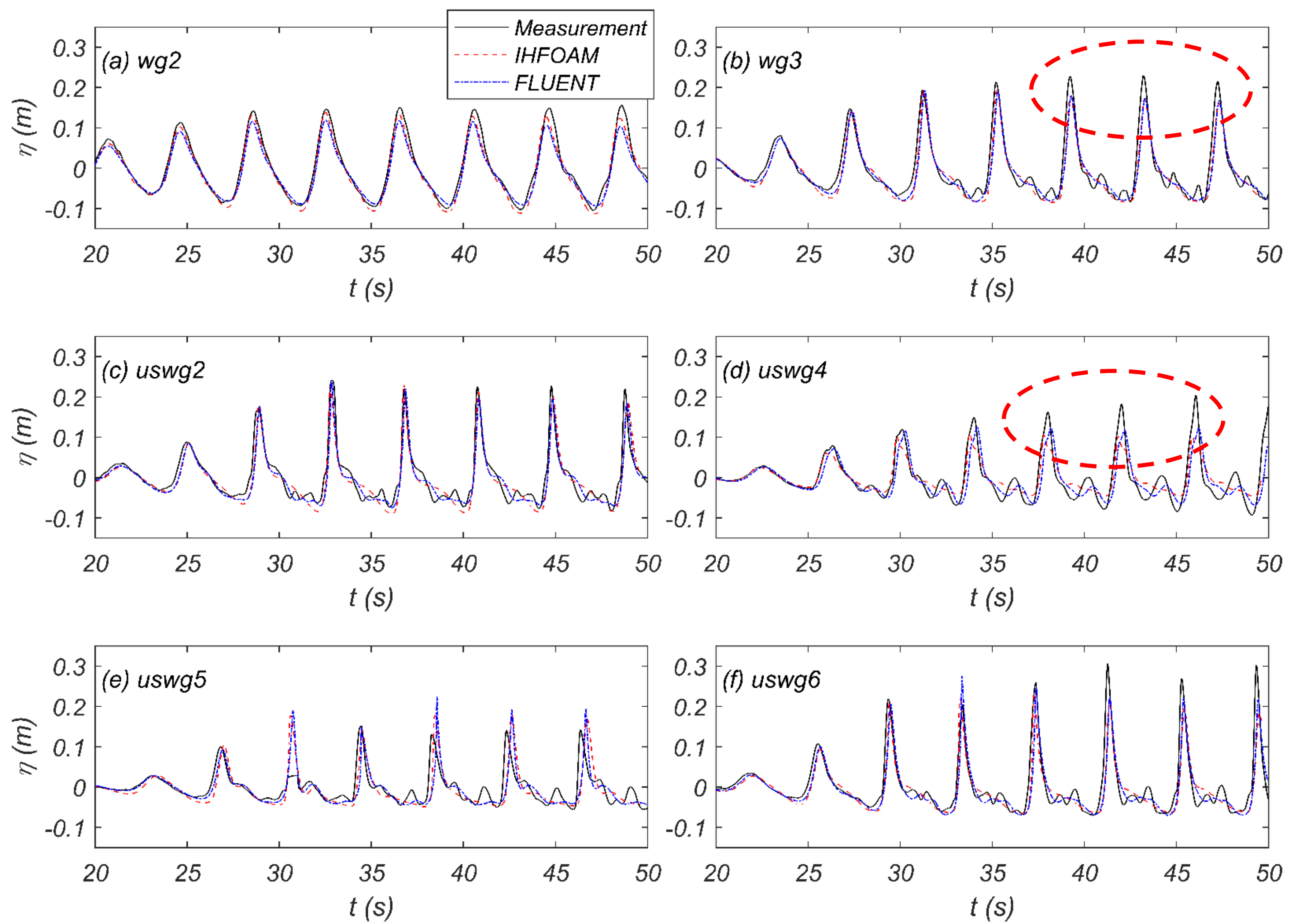
- ➢ Two phase VOF models applied to solve RANS for both for IHFOAM and FLUENT.
- ➢ K-Epsilon models for turbulent.
- ➢ Kept the same range of mesh size, but no sharing the meshes between two models.

	Physical model animation	IHFOAM animation
Non-breaking H = 0.2 m T = 4.1 sec		
Impulsive wave H = 0.26 m T = 3.6 sec		
Broken wave H = 0.40 m T = 4.1 sec		

4. Model results and validation

Surface elevation (non-breaking)



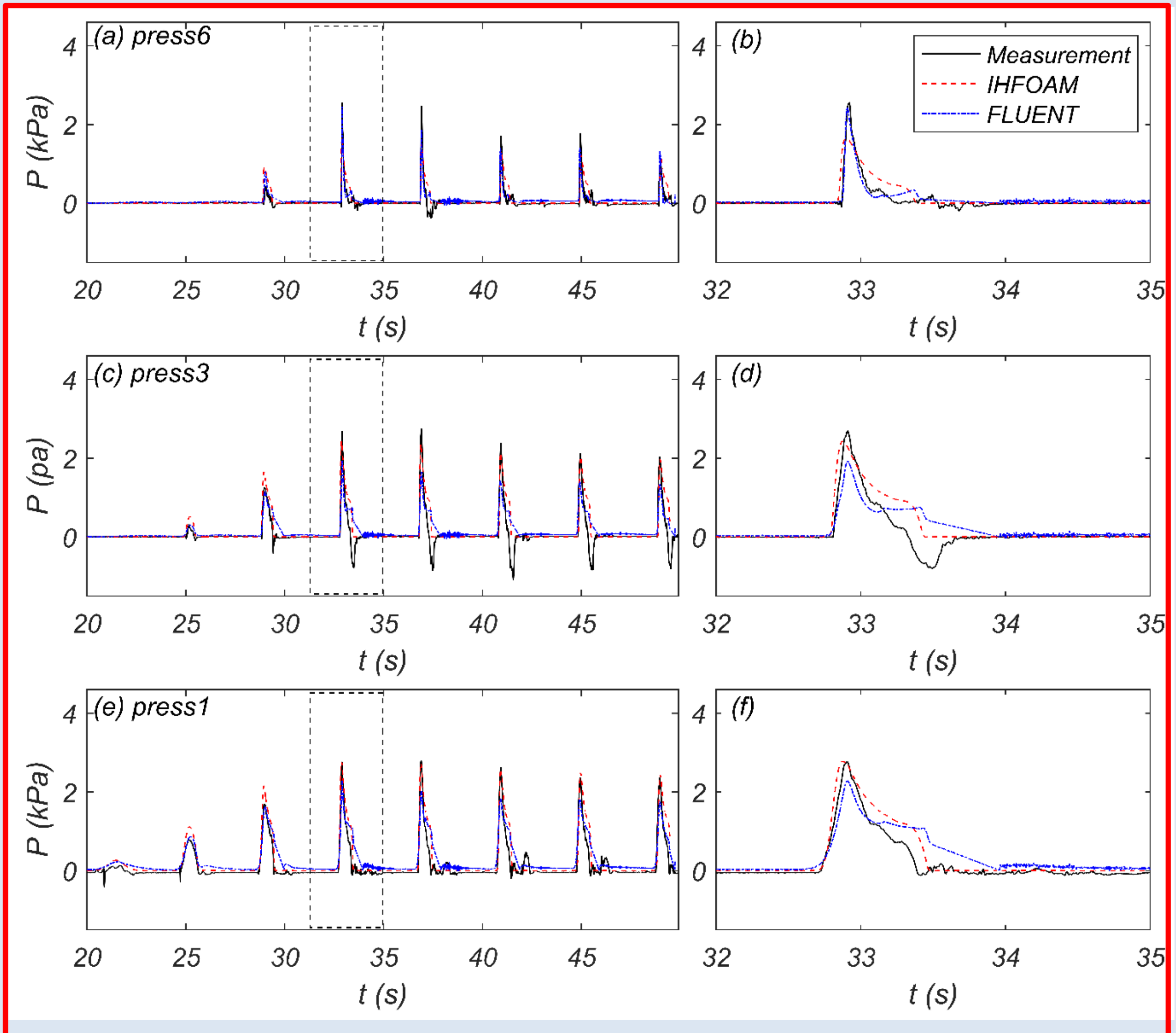


- In general, the both model results show good agreement to the measurements.
- More deviation found after a certain time (e.g. after 37 sec).
- Vibration of the frame induce the differences at the tails.

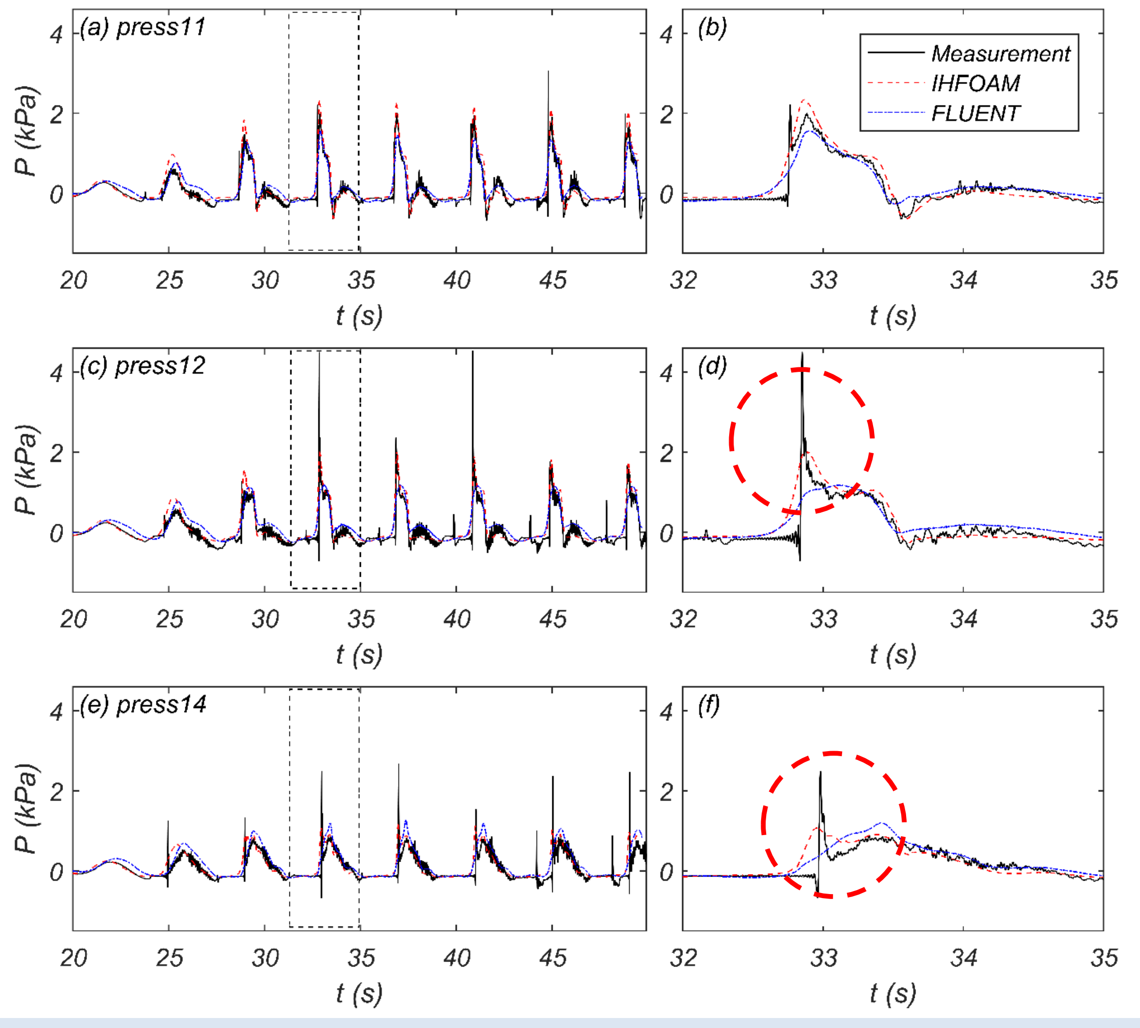
Pressure comparison (non-breaking)

- Peaky pressures are observed at bottom from the measurement, but both CFD models could not capture them.

At front

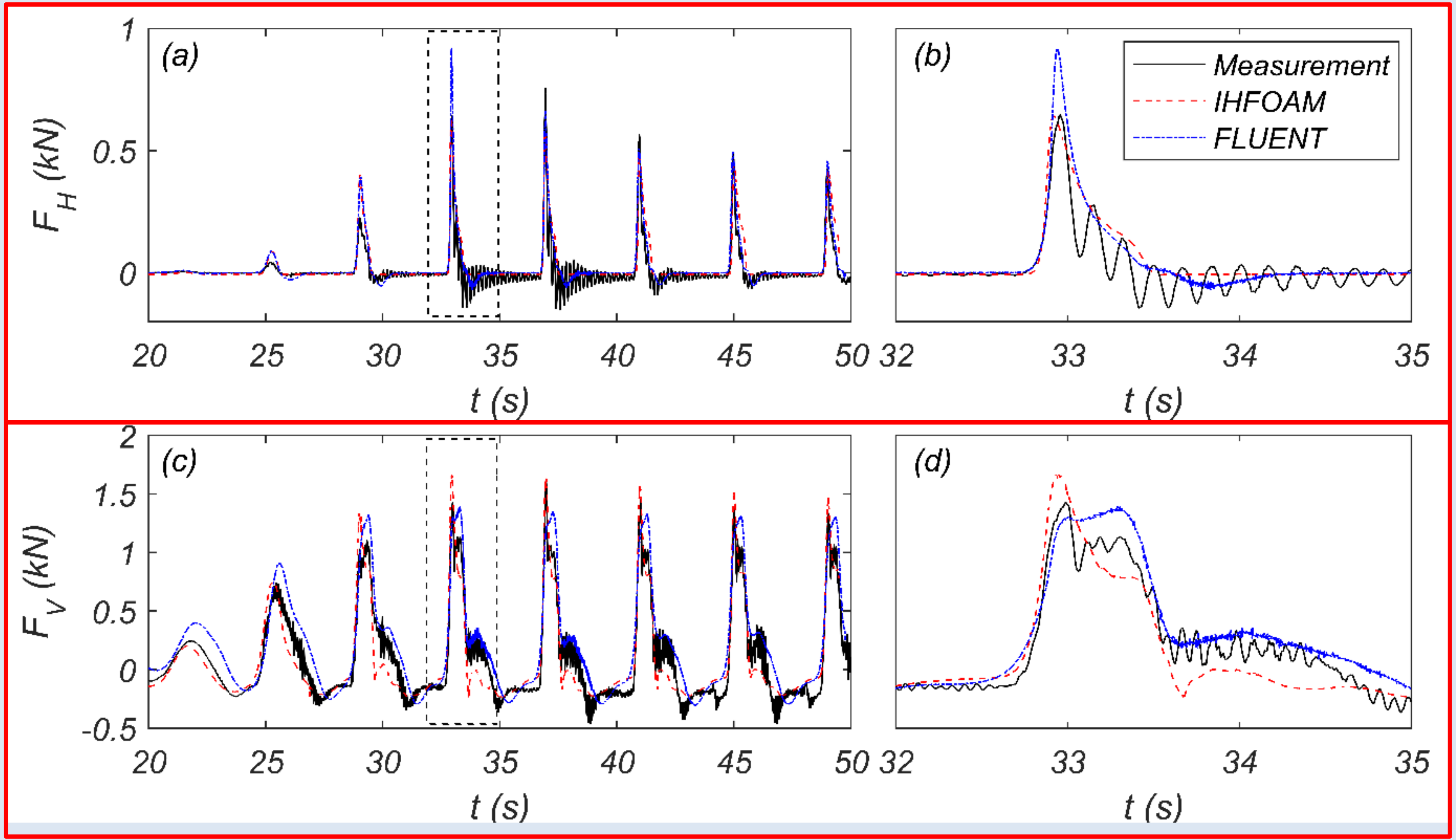


AT bottom



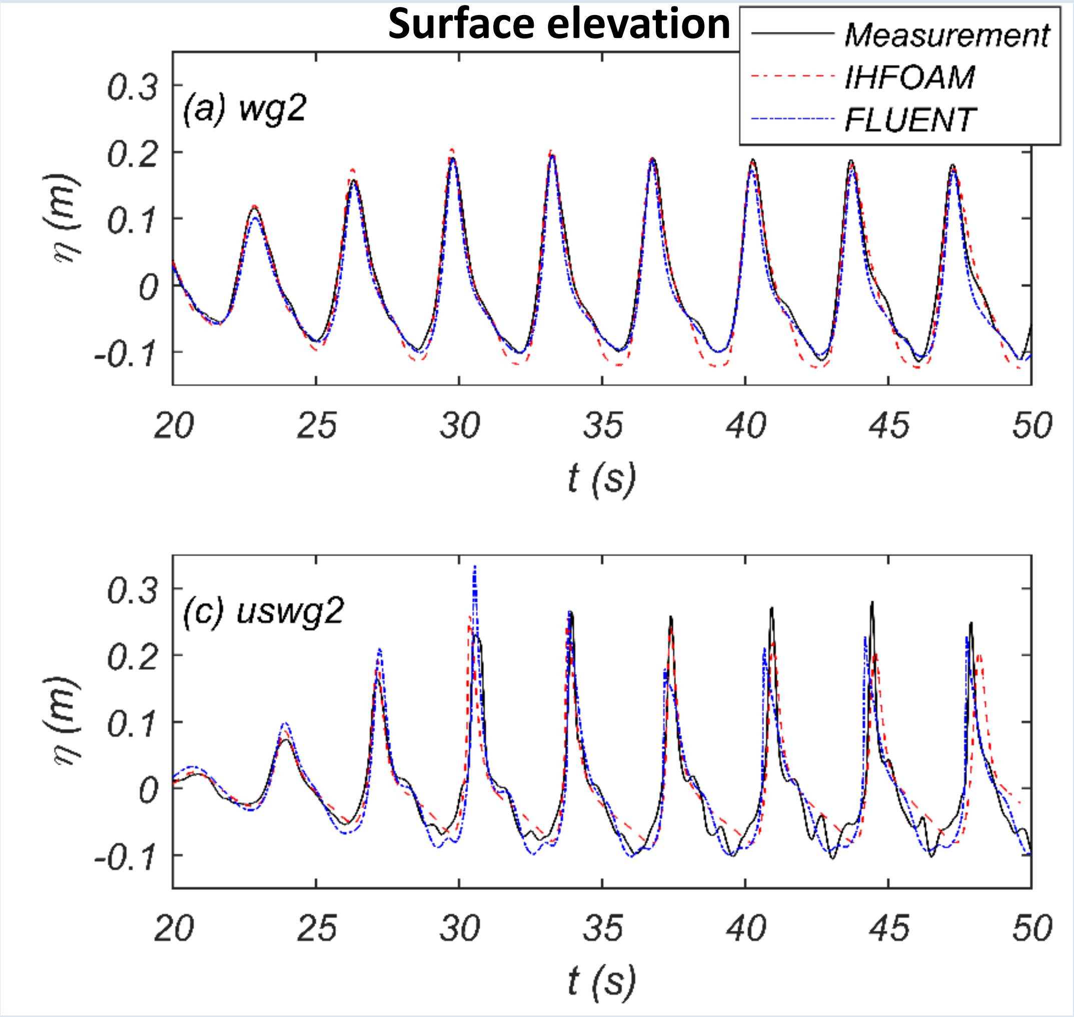
Force comparison (non-breaking)

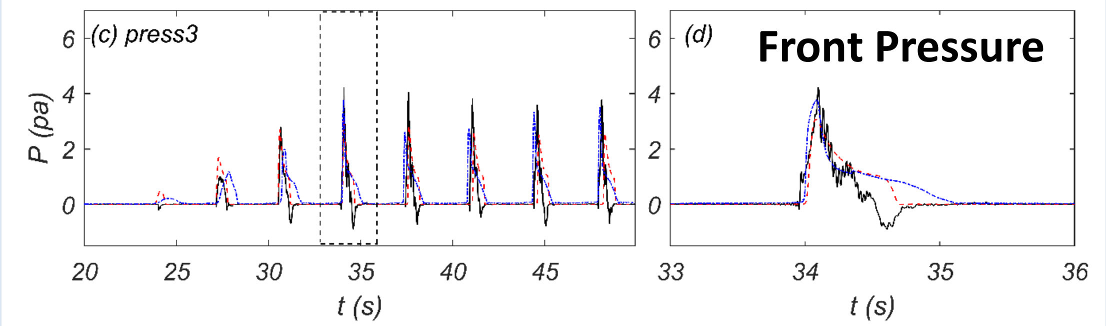
- Damping effects at the physical models, but not in the numerical model.
- Overall horizontal and vertical force comparisons show good agreement even we could not capture peaky pressure at bottom.

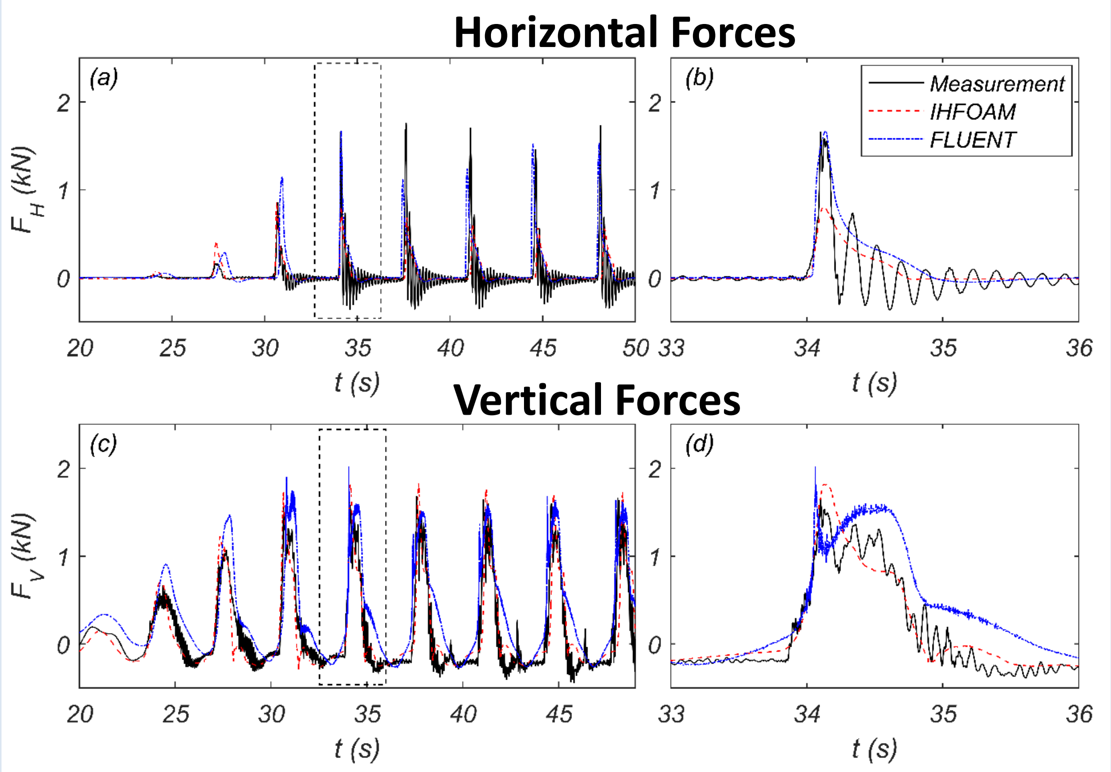


Impulsive wave conditions

- Overall, IHFOAM underestimate the peak surface elevation, pressure and F_H
- IHFOAM couldn't catch the exact impulsive impact at the specimen.

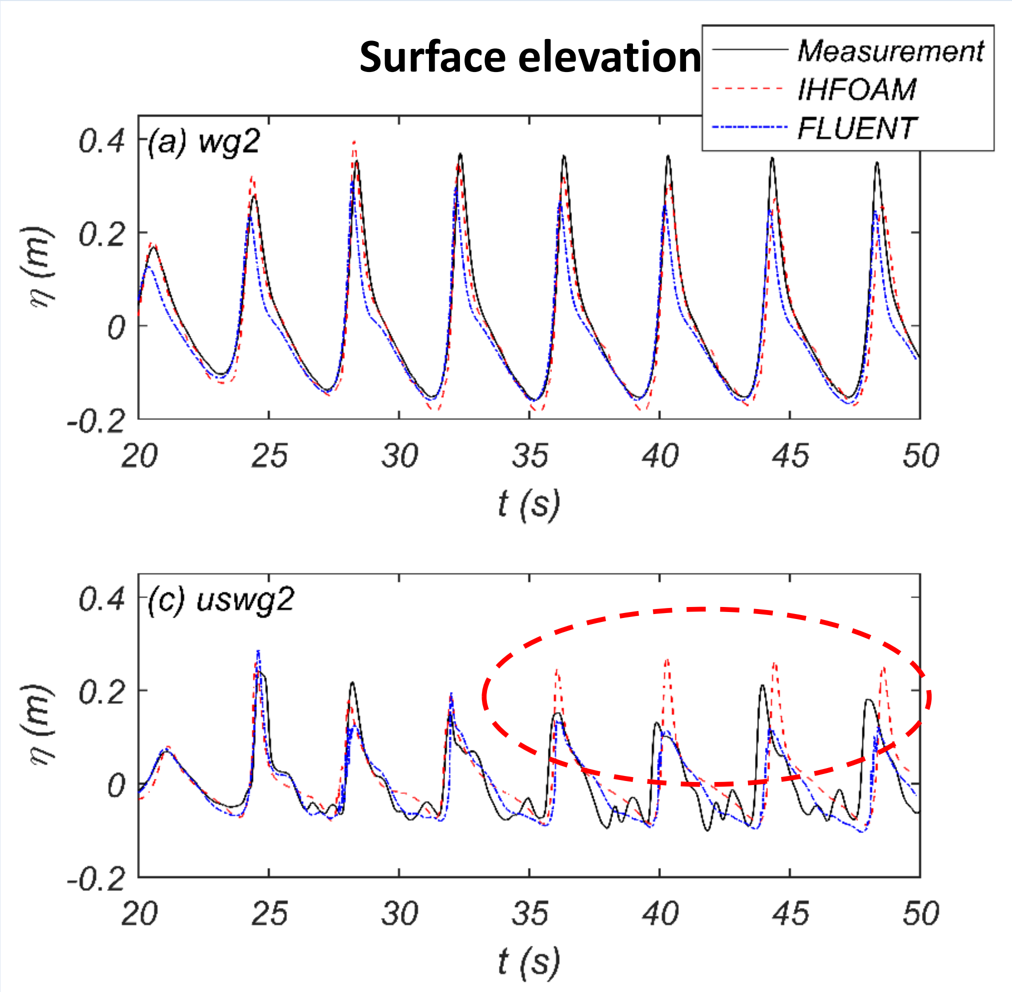


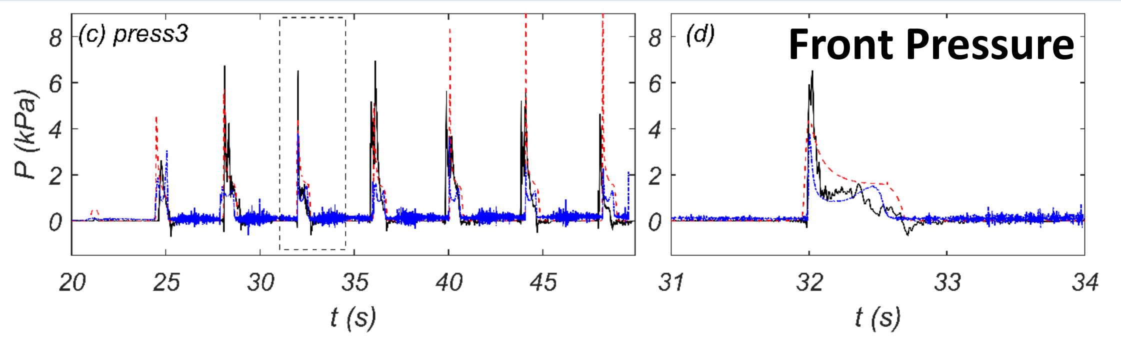


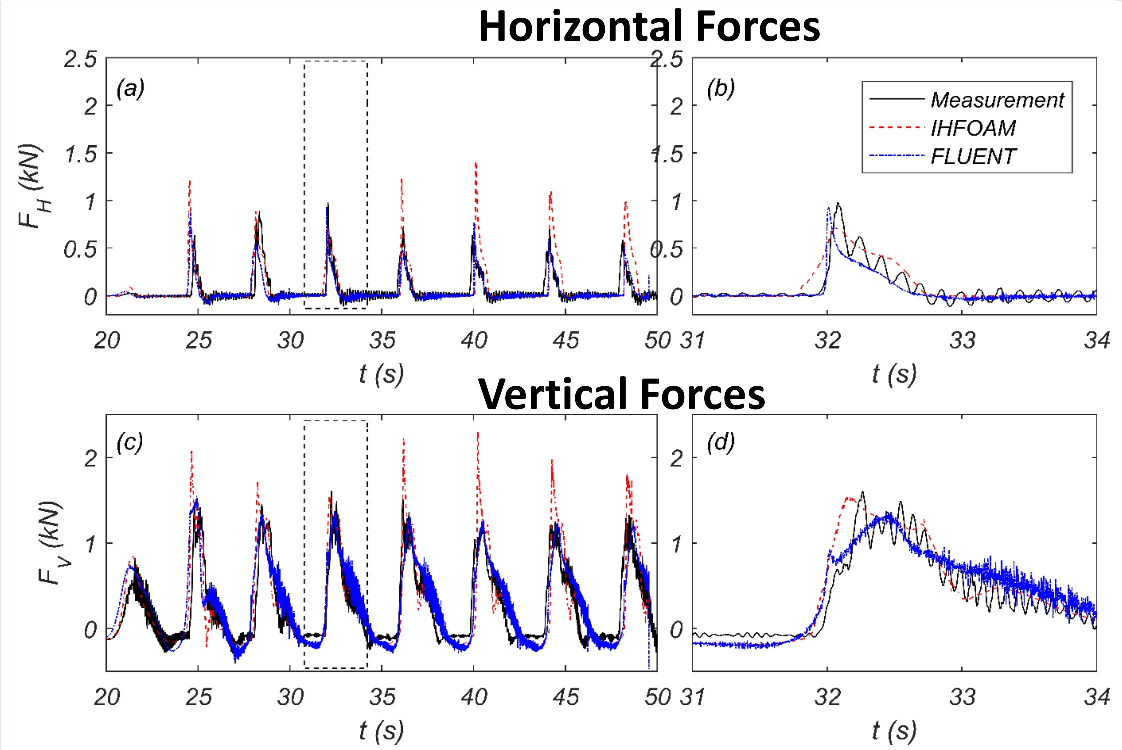


Broken wave condition

- Overall, IHFOAM overestimates all values after 35 s, and it starts to delay.
- It causes from the reflection or Interaction between water and structure which is not simulated in CFD models.







Alternative comparison using a ratio of Residual Impulse (R_J)

- Impulse (per unit area) of the measurement

$$J_X = \int_{t_1}^{t_2} |X| dt$$

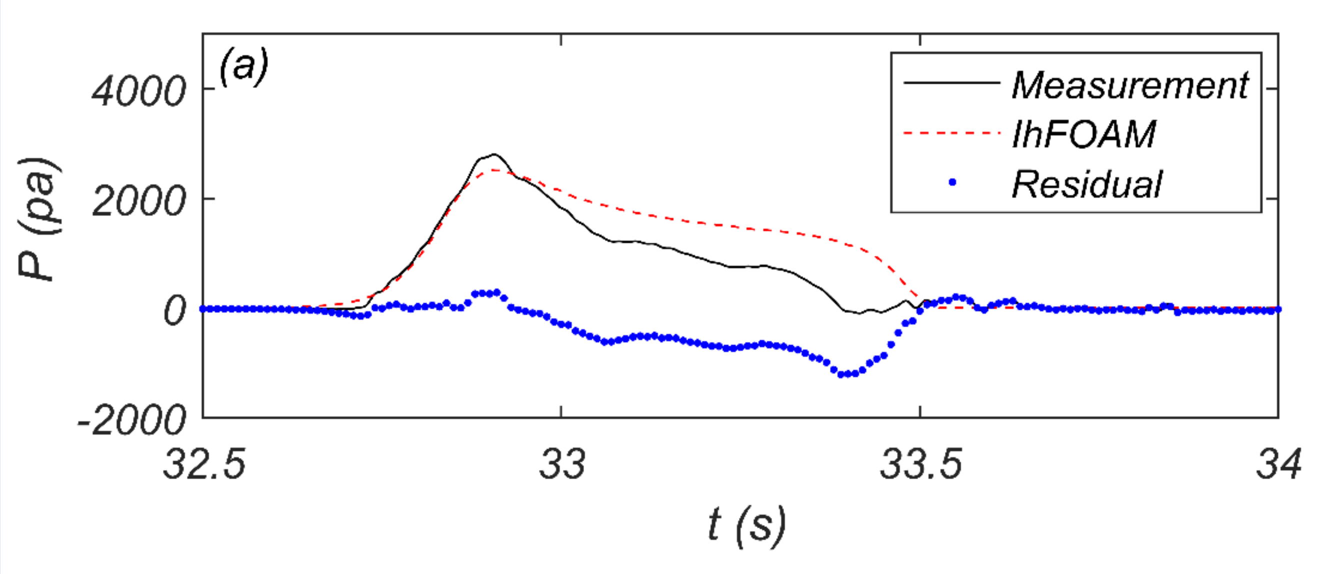
From 4th wave and for 4 continuous waves.

- Residual of Impulse (per unit area)

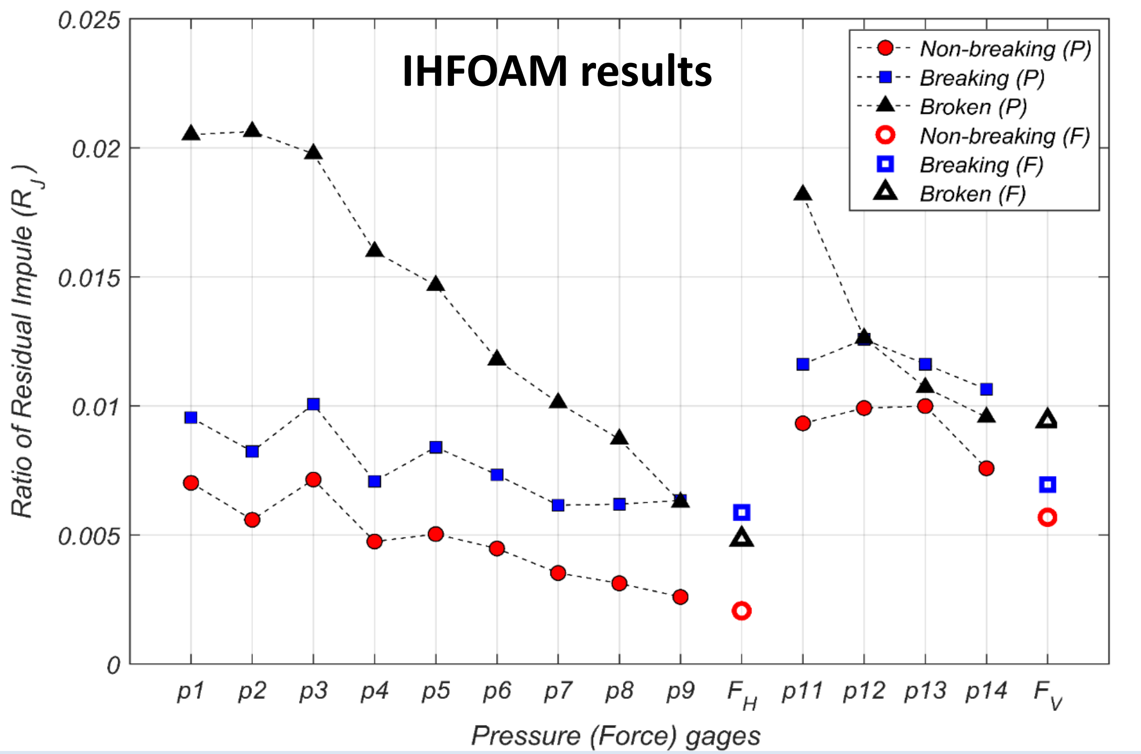
$$J_R = \int_{t_1}^{t_2} |R| dt$$

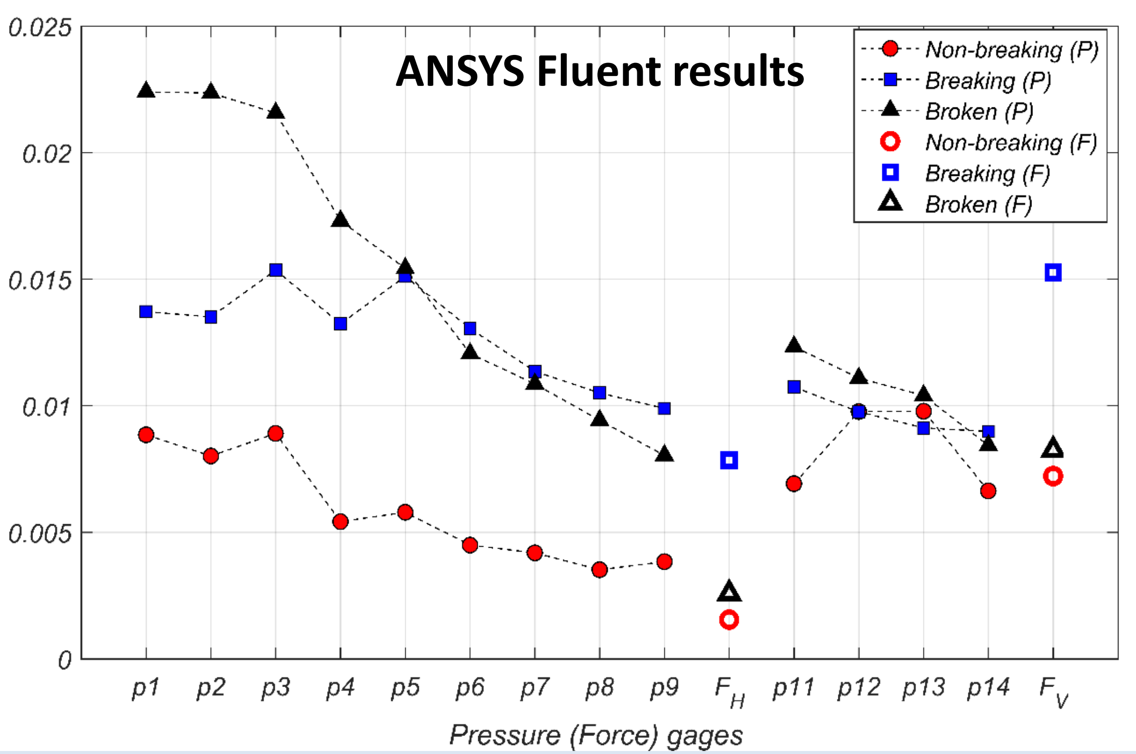
- Ratio of Residual Impulse

$$R_J = \frac{J_R}{J_X}$$



Inter-models comparisons





- Overall, both model shows the similar pattern of R_J (Non-breaking < breaking (Impulsive) < broken wave)
- At both models, higher R_J observed at p1 and p11 at broken wave condition for both models.
- Generally, forces show smaller R_J than the pressures.

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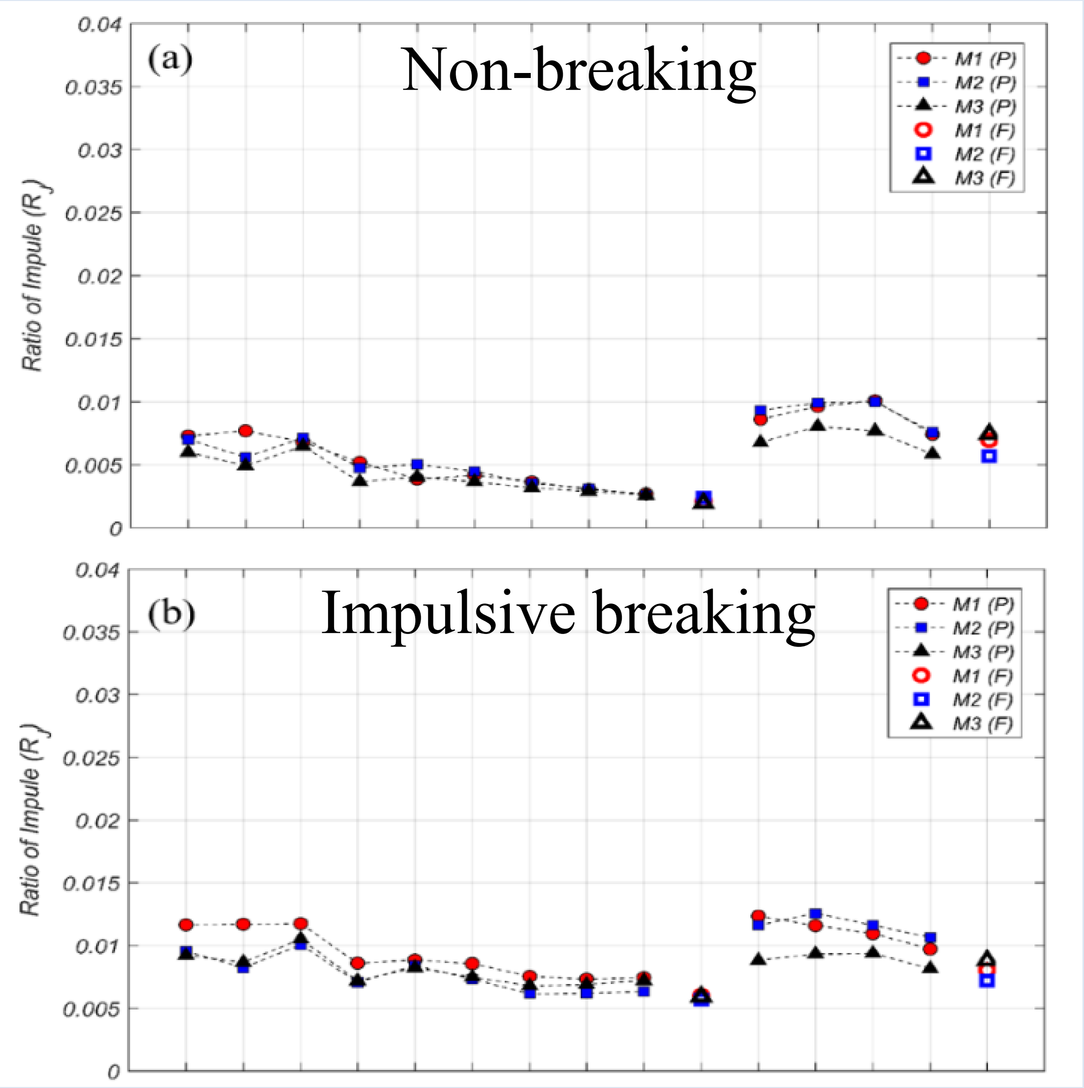
Sensitivity of mesh setup (IHFOAM only)

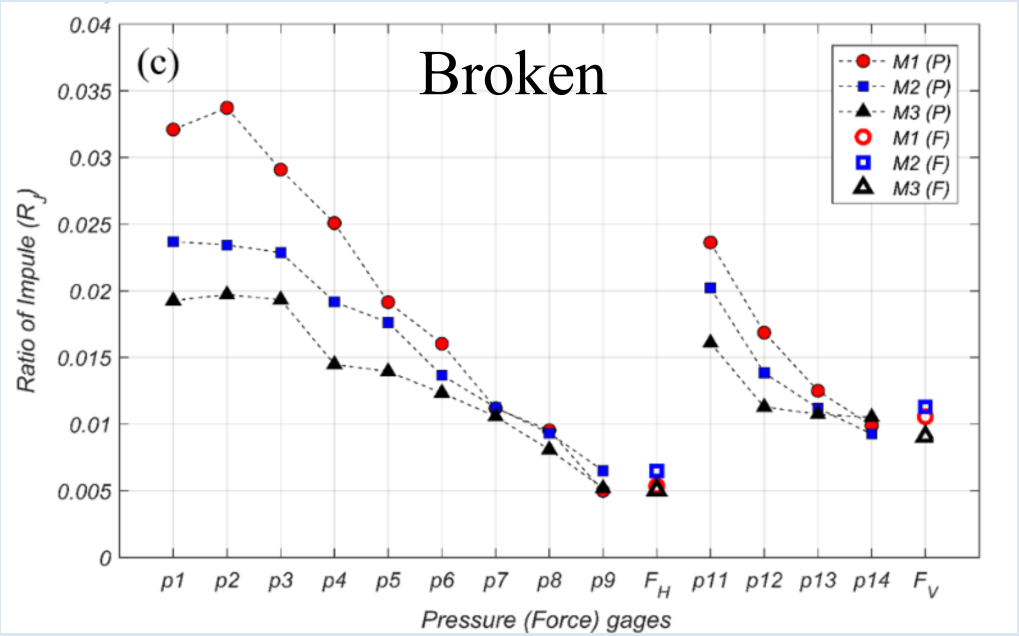
3 type of Mesh sizes

Mesh	Mesh Types		
	M1 (Coarse)	M2 (Medium)	M3 (Fine)
dx (m)	0.08 – 0.2	0.04 – 0.1	0.02 – 0.1
dz (m)	0.08 – 0.2	0.04 – 0.1	0.02 – 0.1
dy (m)	0.08 – 0.16	0.04 – 0.08	0.02 – 0.05
Number of elements	505,125	1,010,385	3,149,370
Courant number	0.5	0.5	0.5
Number of CPU	4-Core	4-Core	4-Core
Computation time	3 hr	10 hr	127 hr

* Total 40 second regular wave runs were simulated through a desktop with i7-4770 and 64G RAM with 4-core parallel.

Mesh sensitivity for three wave conditions



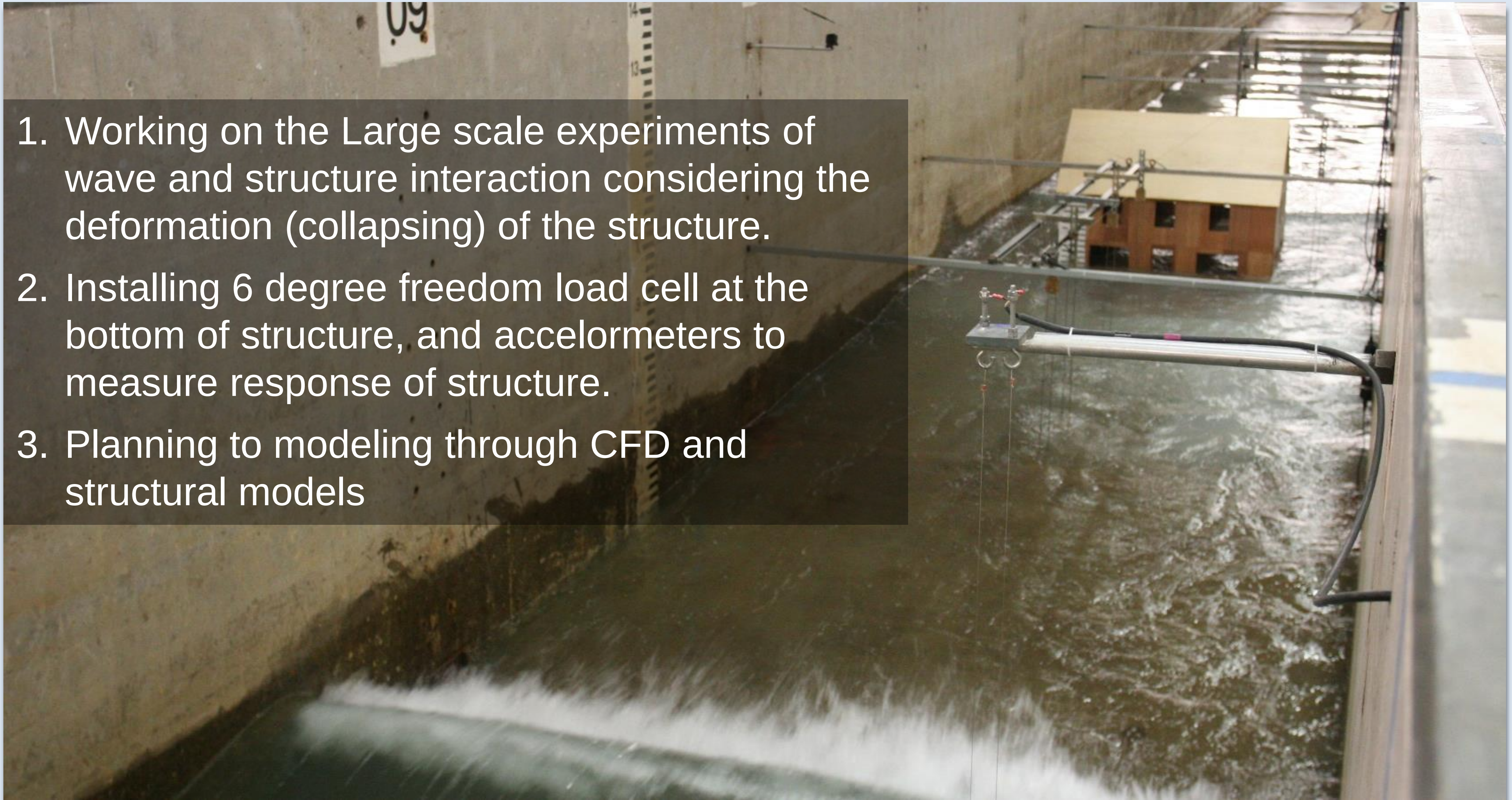


- Significant different R_J is found at pressure for broken waves, while no significant deviations of R_J for forces.

Conclusion

1. Generally, the largest deviation is found at pressure while the smallest deviation at surface elevation for both IHFOAM and FLUENT models.
2. The performance of CFD models significantly different depending on the wave conditions. Relatively small deviation is found at non-breaking, but relatively large deviations found at impulsive and broken wave conditions.
3. It is difficult to calculate peaky pressures, but they did not induce significant impacts on the total forces.
4. The increased deviation of surface elevations after a certain time, due to wave and structure interaction or reflection could propagates significantly to the pressure (force) calculation, especially at breaking and broken wave.
5. Overall, finer mesh provided improved results, but relatively minor impacts on the surface elevation and force. However, the major effects were found at pressure calculations, especially for broken wave conditions (IHFOAM).

Current and Future Works



1. Working on the Large scale experiments of wave and structure interaction considering the deformation (collapsing) of the structure.
2. Installing 6 degree freedom load cell at the bottom of structure, and accelormeters to measure response of structure.
3. Planning to modeling through CFD and structural models

Advertisement

There are two more presentations introducing the application of the physical modeling of the elevated structure.

1076 - Application And Modification Of Goda Formulae For Nonimpulsive Wave Forces On Elevated Coastal Structures

Thursday, August 2 4:40 PM - 5:00 PM Location: Grand Ballroom I & II

Presenting Author(s)

Tori Tomiczek, PhD
Assistant Professor
United States Naval Academy

1644 - Experimental Modeling Of Wave Forces And Hydrodynamics On Elevated Coastal Structures Subject To Waves, Surge Or Tsunamis: The Effect Of Breaking, Shielding And Debris

Friday, August 3 11:20 AM - 11:40 AM Location: Essex

Presenting Author(s)

Pedro Lomonaco, PhD
Director, O.H. Hinsdale Wave Research Laboratory
Oregon State University

Thank you

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Appendix

Sampling rate

- All measurement is fixed as 500Hz
- CFD ranged 100 to 1000 Hz depending on computation time step
  (e.g. M3, IHFOAM, non-breaking)

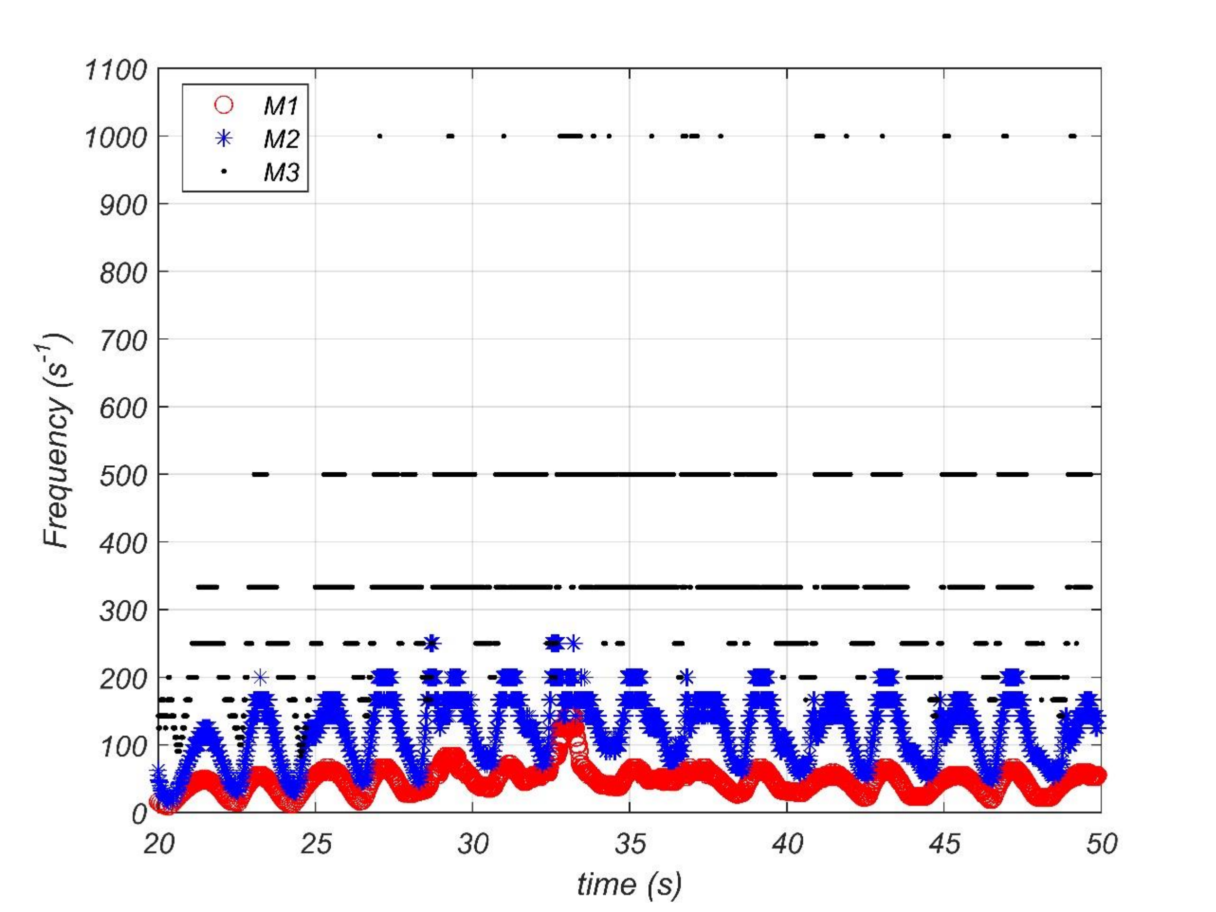
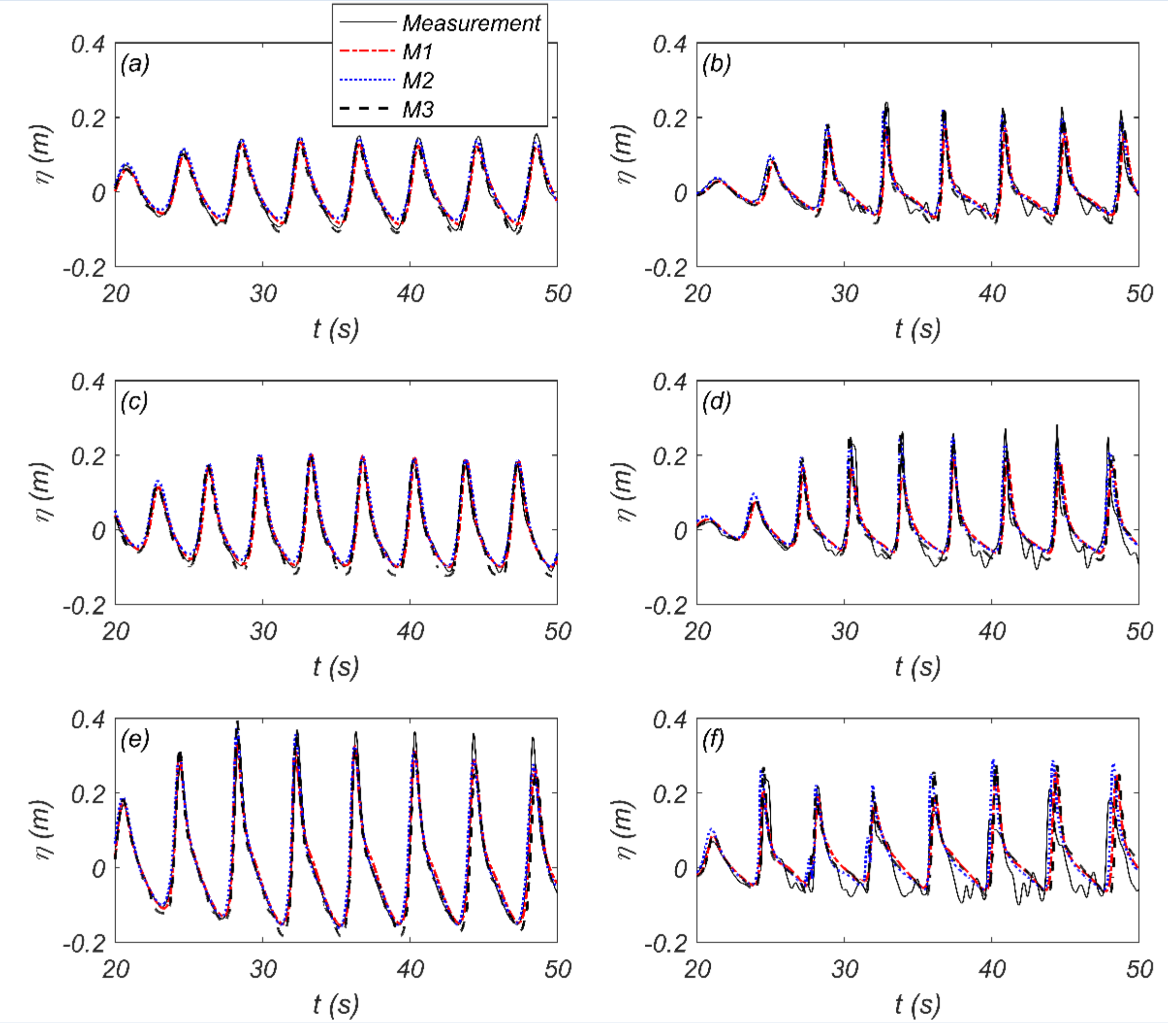
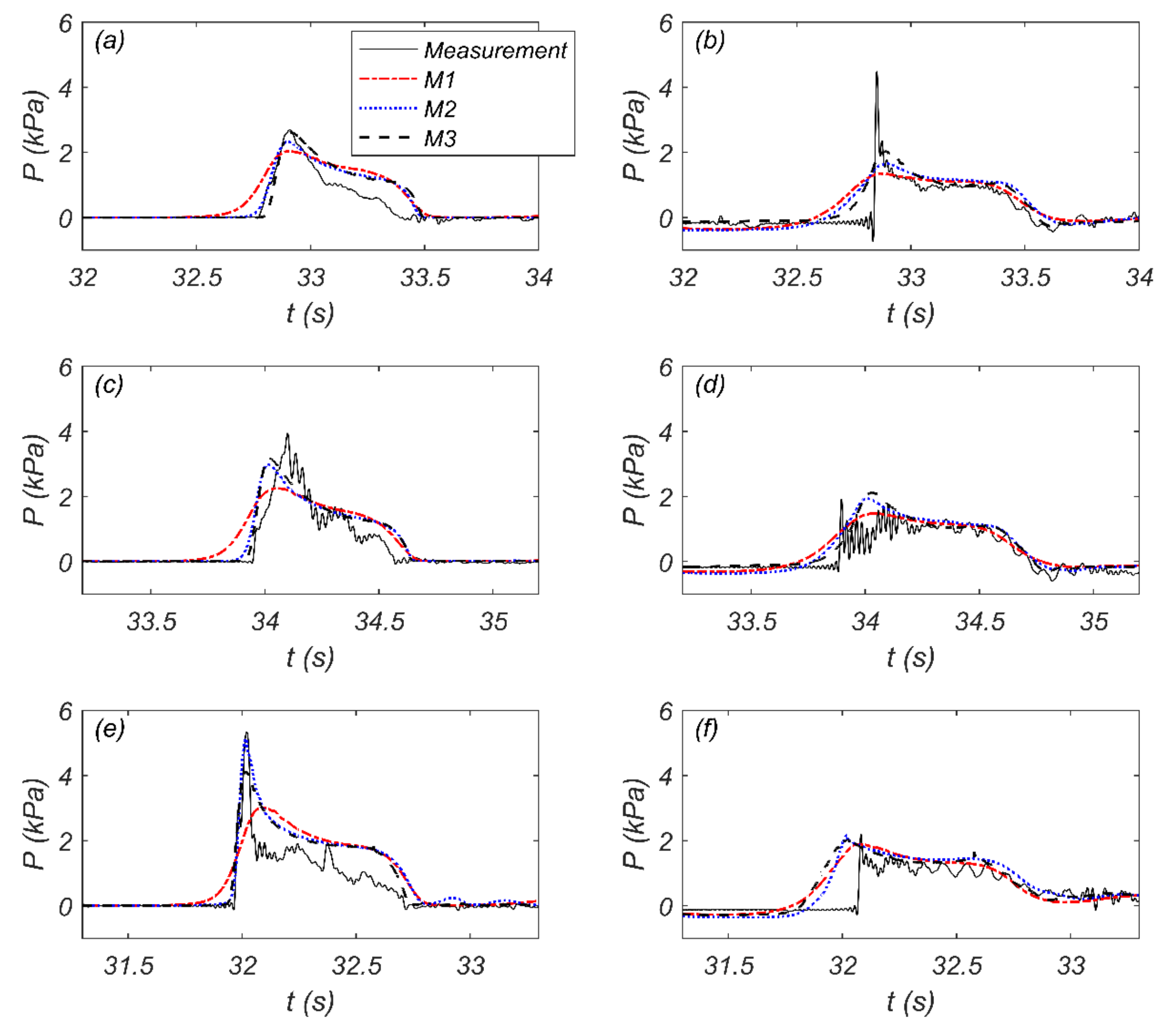


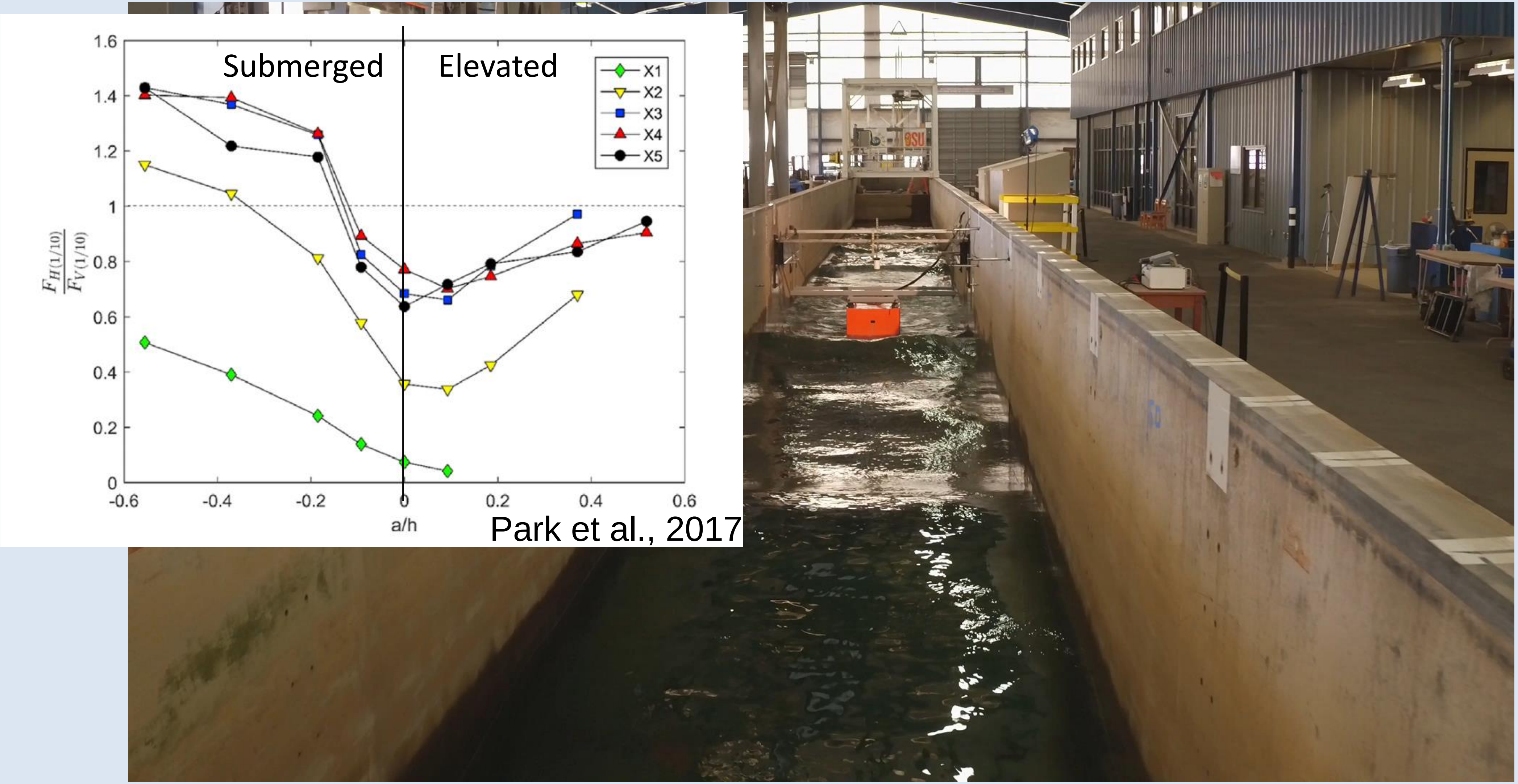
Fig. A1 Frequency of calculation time step of each mesh conditions for X2 (non-breaking wave, IHFOAM)

Different mesh conditions



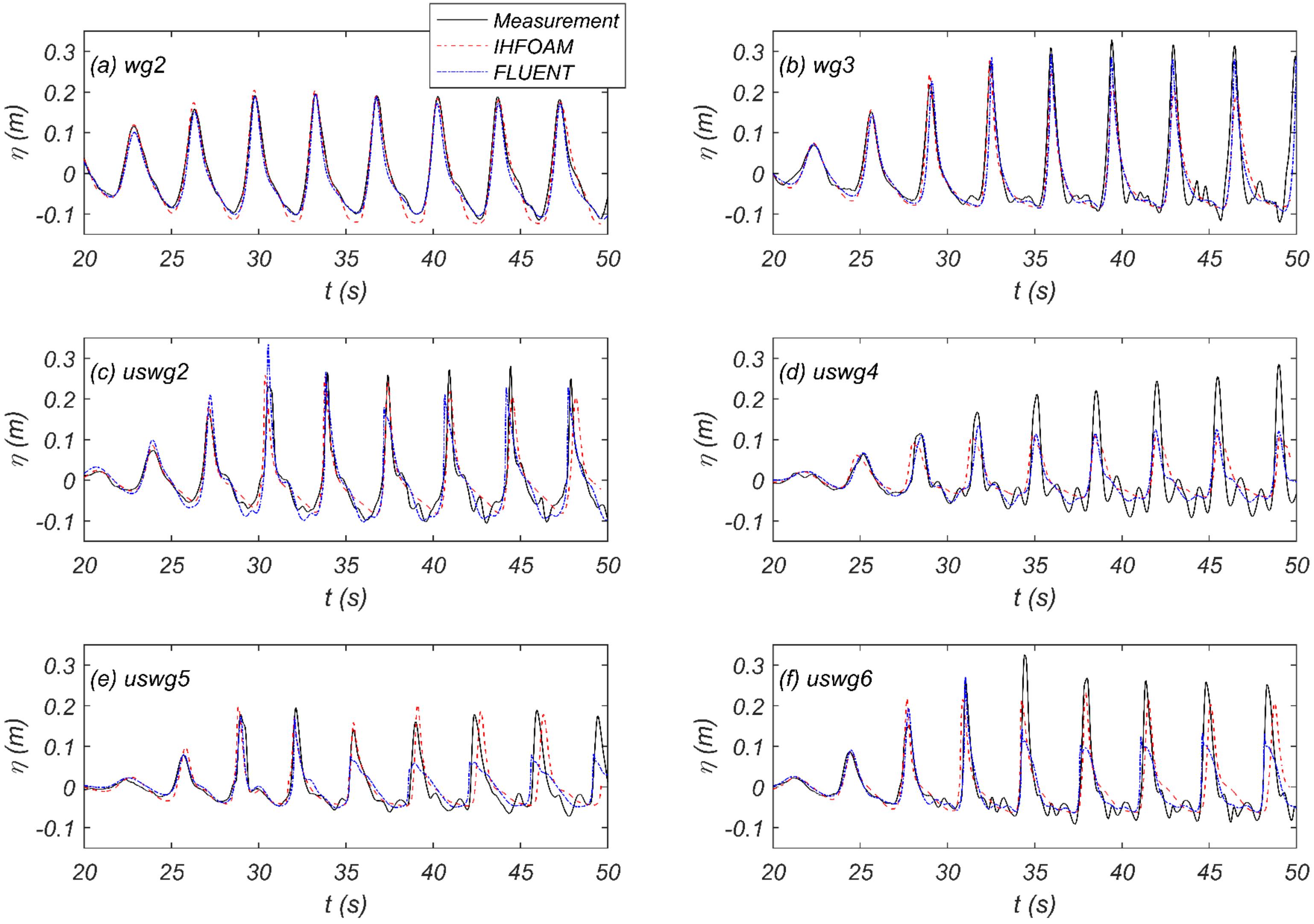


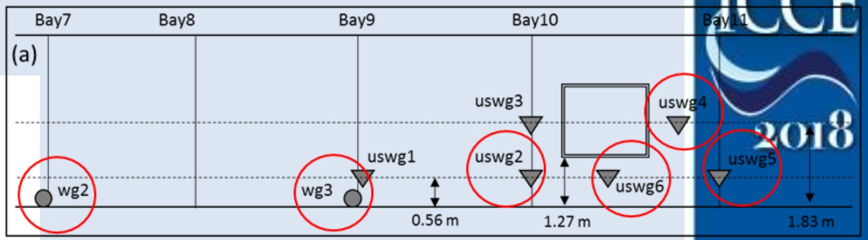
Example movie, TMA, H_s=0.29; T=4.1 s; a=0



Park et al., 2017

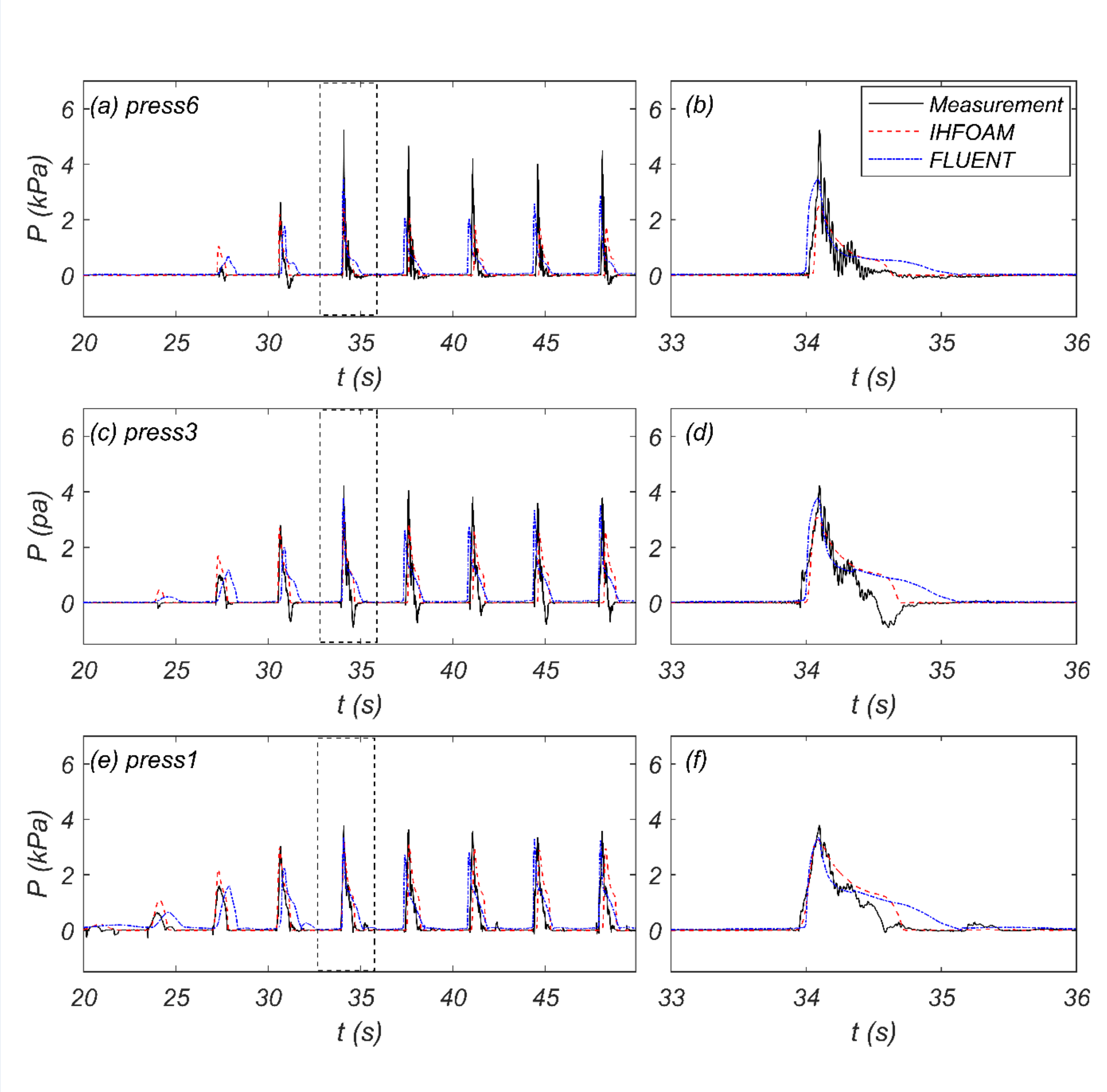
Model validation of surface elevation (Breaking, X8)

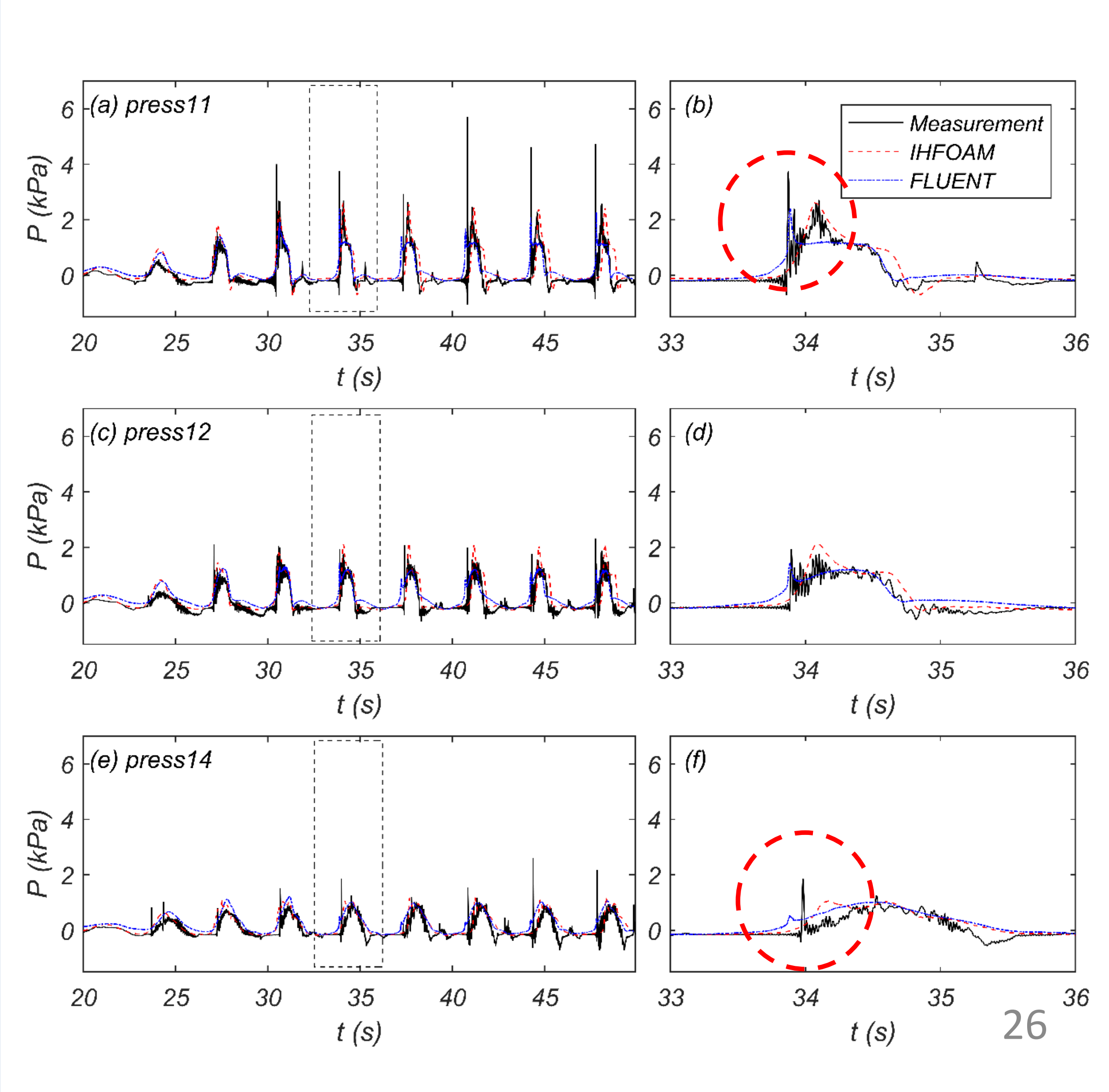




- Both model results show similar pattern.
- Slightly underestimate the surface elevation at wg3 and uswg2. (less shoaling)
- Still differences at the wave tail and uswg4 shows the largest deviations.

Model validation of pressure (breaking, X8)





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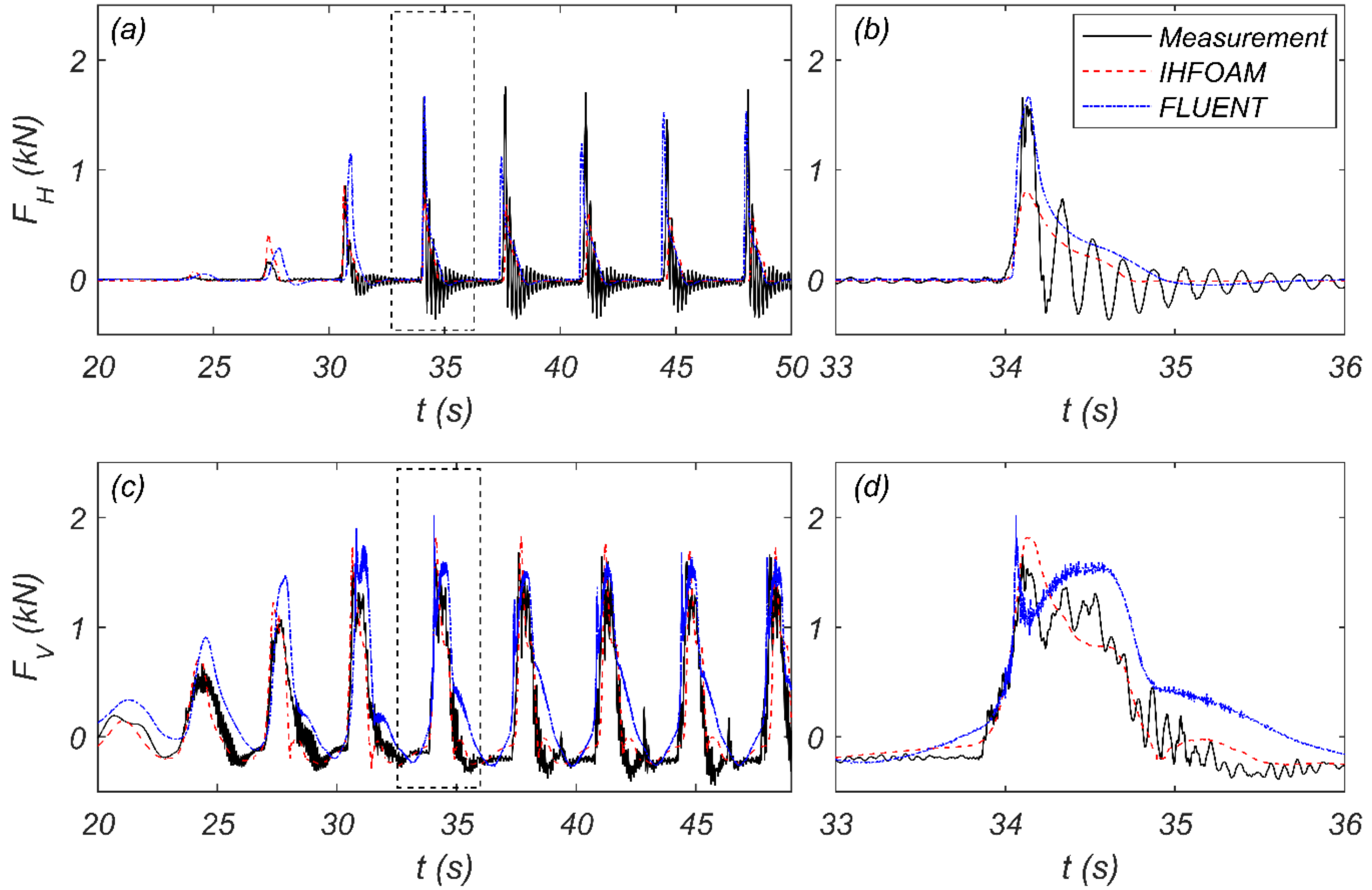
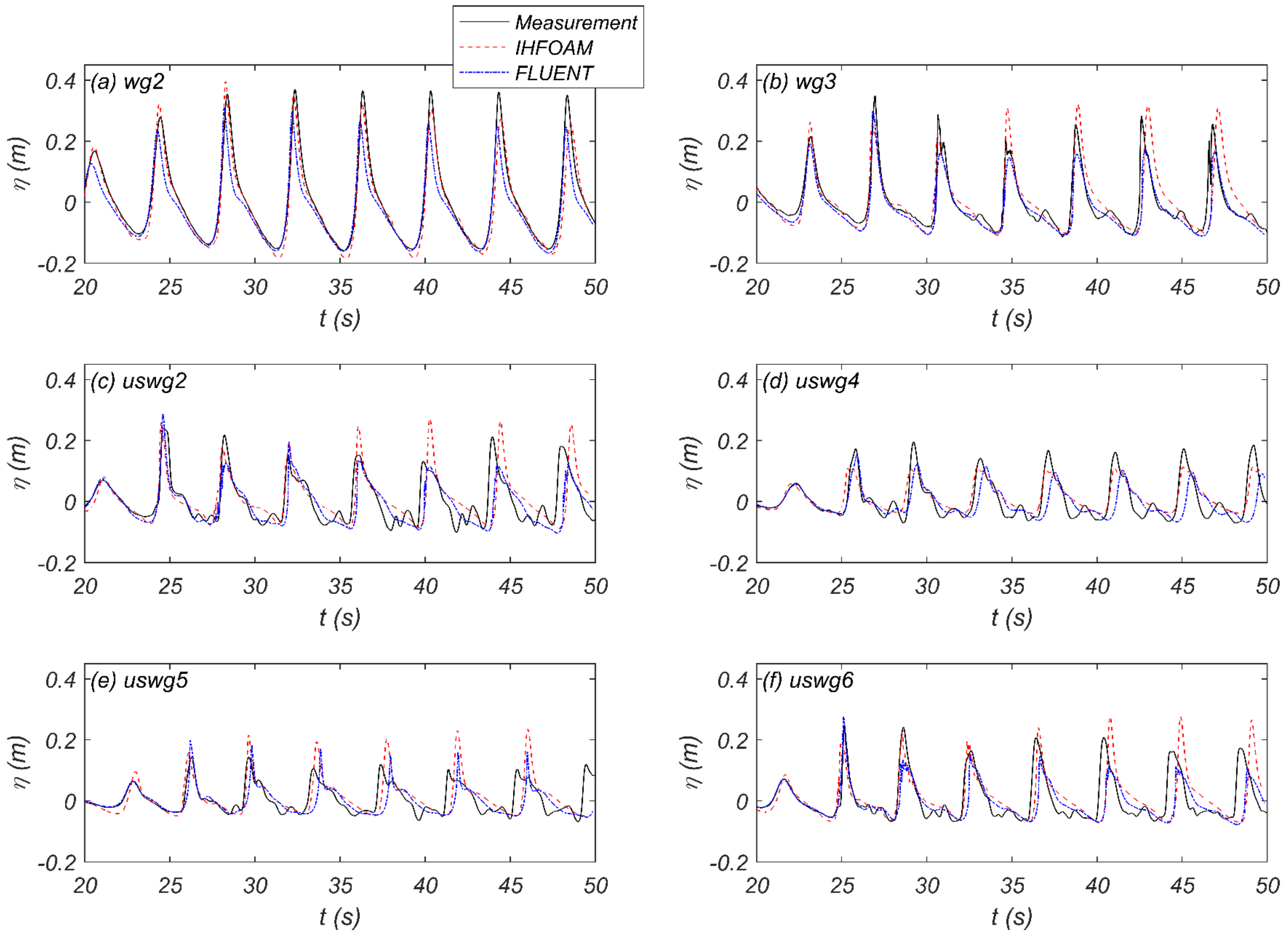
Model validation of forces (breaking, X8)

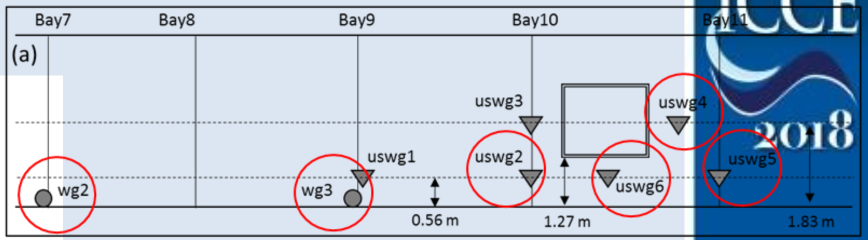


- IHFOAM underestimates F_H, rather than FLUENT, But IHFOAM show better performance at F_V

- Underestimations are generated from the smaller wave height at wg3 and uswg2. (tend to break earlier than the experiment)

Model validation of surface elevation (Broken, X4)





- Slightly overestimate the surface elevation at wg3 and uswg2 after 35 sec, while FLUENT underestimate at wg2.

- Uswg2 and uswg5 shows the largest deviations (IHFOAM)
  (It tell us that numerical results break late.)

- At uswg4, it show good agreement, to compare with other wave conditions

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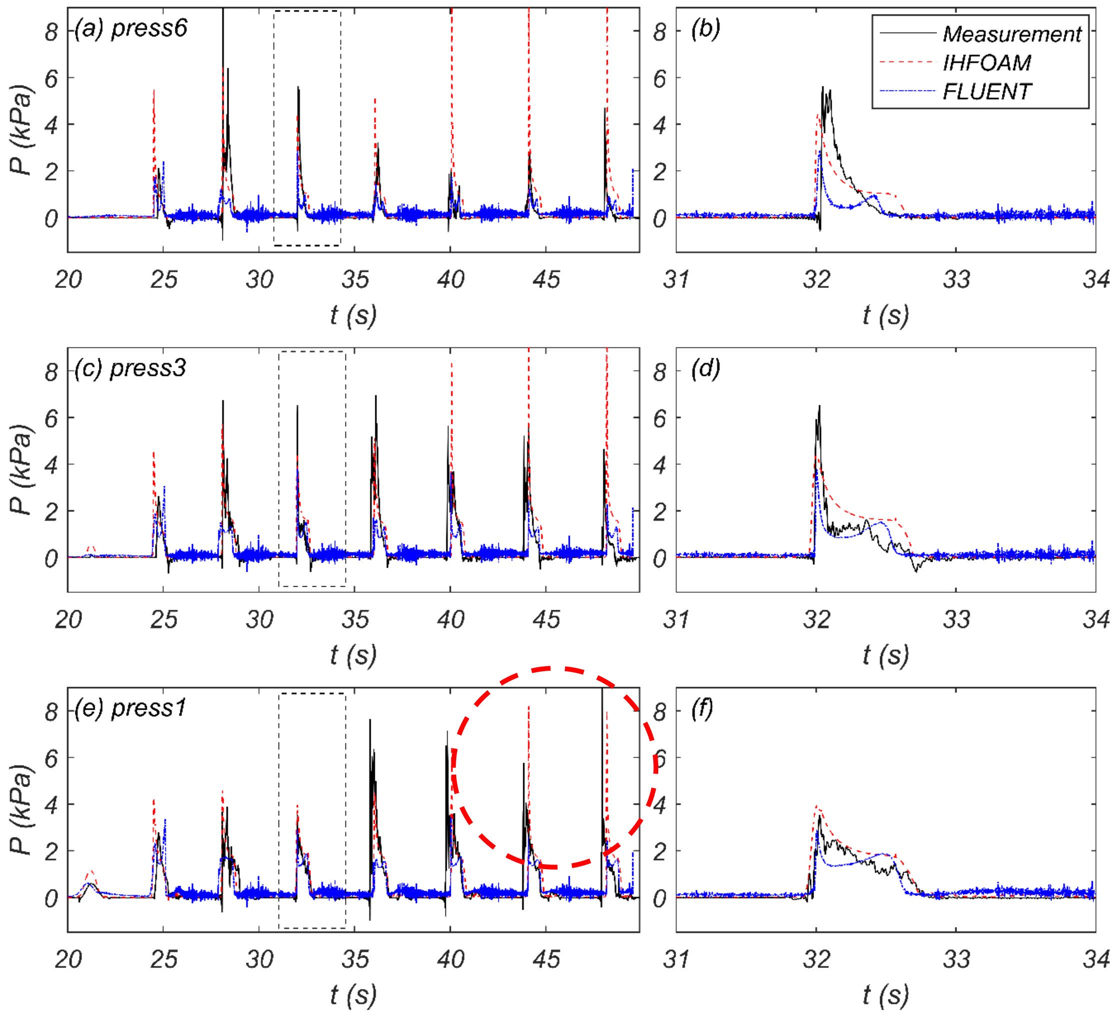
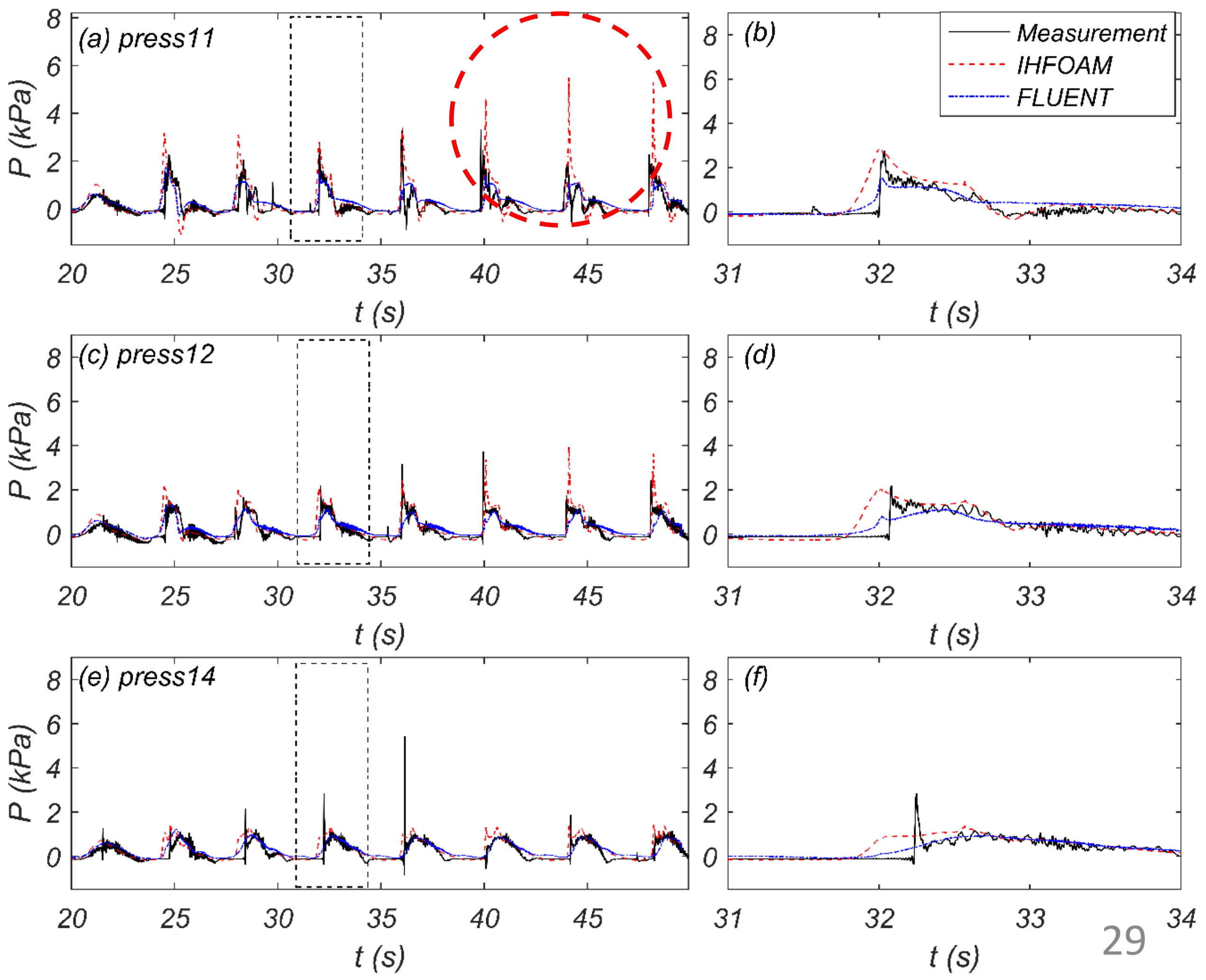
Model validation of pressure (broken, X4)

- Overestimation (IHFOAM) after 35 sec





- Generally IHFOAM results overestimate the both peak values.
- Those overestimates are generated from the overestimated wave height at wg3 and uswg2 after 35 sec.