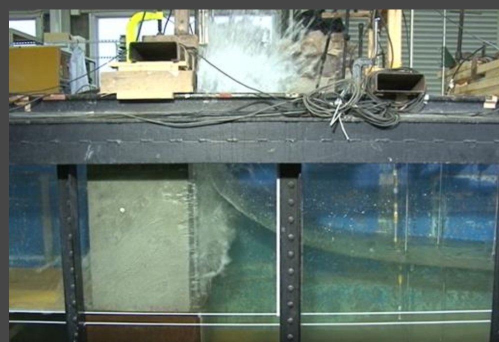
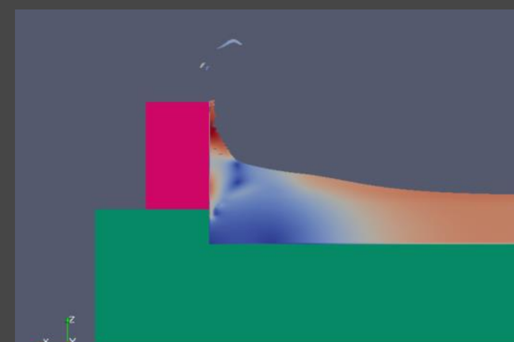
Comparison of Numerical Wave Tanks with Various Turbulence Models in Application to Long Wave Motion and Its Interaction with a Vertical Wall





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Motivation

- 2011 GEJE Tsunami – failure of coastal defense structures
- Importance of tsunami-structure interaction studies in design of coastal structures
- Role of numerical modelling
- Physical model experiments on tsunami-vertical wall interaction performed by Arikawa (2015) at Port and Airport Research Institute (PARI), Japan
- Numerical modeling of benchmark experiments using **interFoam**, a solver developed in **OpenFOAM** environment, and **CADMAS-SURF/3D**.
- In particular, we look into **the effect of turbulence modeling!**

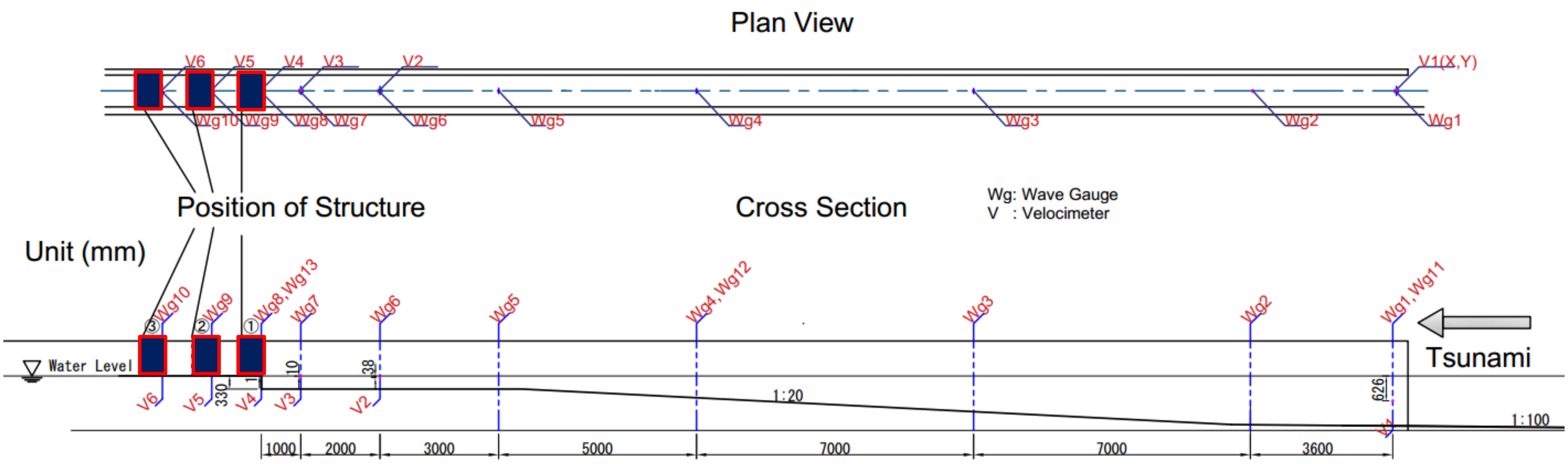
Overview of the Physical Model Experiments

- 105m wave channel of PARI
- 10 wave gauges (WG)
- 6 velocimeters (V)
- Pressure Gauges on the walls (PG)

Vertical Wall Dimensions

Width	Height	Thickness
80 cm	100 cm	50 cm

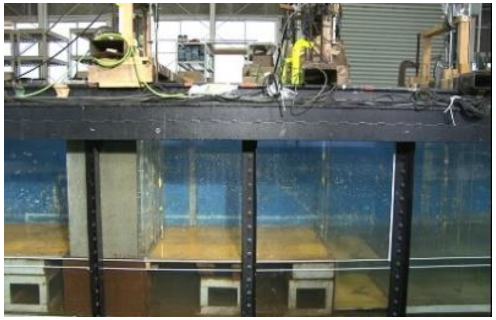
(Arikawa, 2015 (in Japanese))



Overview of the Physical Model Experiments

- Solitary wave attack towards the vertical wall is studied!
  - In order to understand the effect of the tsunami-like long waves
  - 3 cases (Different vertical wall locations)

Case 1



Case 2

Case 3

Numerical Modelling Studies

interFoam

- *interFoam* solves 3D Navier Stokes Equations for two incompressible phases tracking the free surface using Volume of Fluid (VOF) method.
- Finite Volume Method on unstructured grids
- For wave generation and absorption boundary conditions, IHFOAM is used.

(Higuera et al., 2013a; Higuera et al., 2013b)

- Turbulence models (RANS): k-ε, k-ω SST
- Large Eddy Simulation
  - SGS model: Smagorinsky

CADMAS-SURF/3D

- CADMAS-SURF/3D solves 3D Navier Stokes Equations for single incompressible phase with a porous body model and tracks the free surface using Volume of Fluid (VOF) ,
- Finite Differences Method on structured grids
- Turbulence models (RANS): k-ε

Numerical Modelling Studies

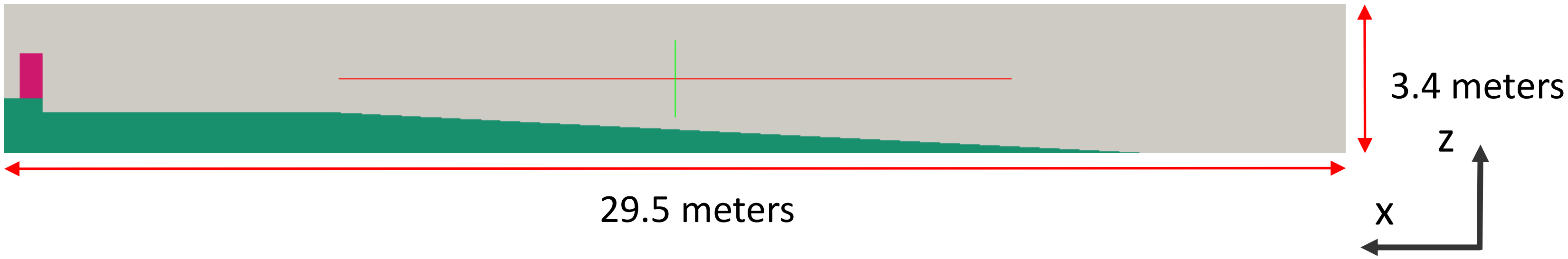
- Numerical simulations performed for Case 1 and Case 3:

Turbulence Modelling	interFoam	CADMAS-SURF/3D
Laminar	✓	✓
k-ε	✓	✓
k-ω-SST	✓	-
LES	✓	-

- Duration: 20 seconds
- Comparisons with experimental results
  - Wave Gauges
  - Velocity Gauges
  - Pressure Gauges

Description of Computational Domain for interFoam

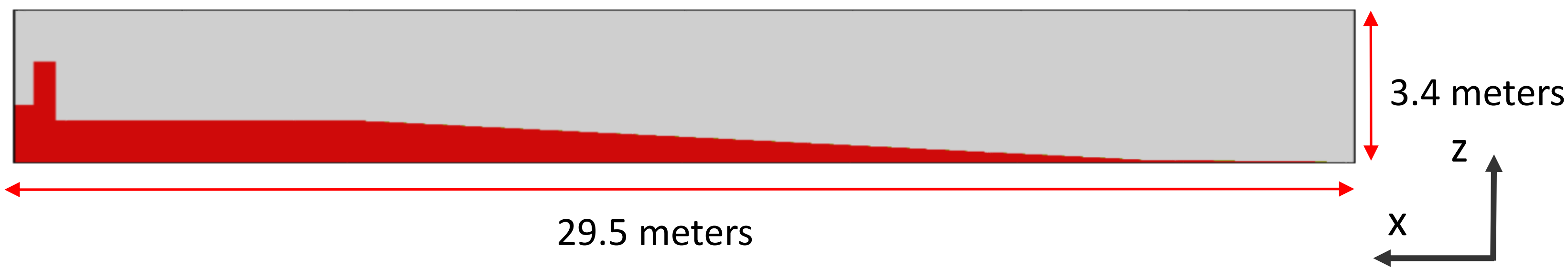
Case 1



- Max dx=5 cm - min dx=1 cm, dz=0.5 cm
- RANS: 1 cell in y direction
- LES: dy=1 cm (10 cells)
- Total Number of Cells: ~ 700,000 (RANS), ~7,000,000 (LES)
- Inlet B.C.: Measured surface elevation and water particle velocity

Description of Computational Domain for CADMAS-SURF/3D

Case 1



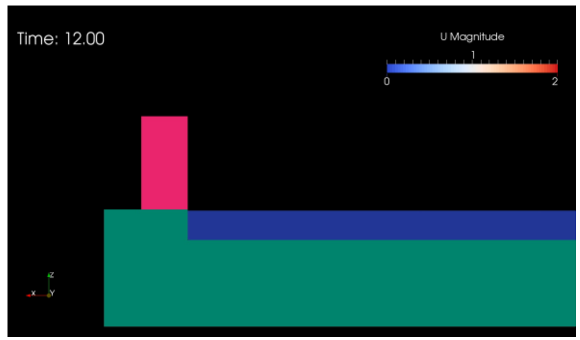
- Max dx=5 cm - min dx=1 cm, dy=2 cm (1 cell), dz=0.5 cm
- Total Number of Cells: ~ 700,000
- Inlet B.C.: Measured surface elevation and water particle velocity

Comparison of Physical Model Experiment and Numerical Model Simulations

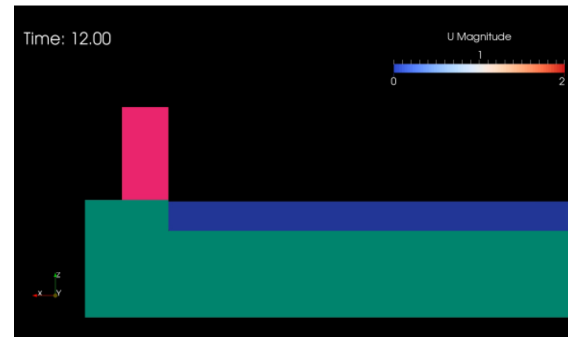
interFoam

Case 1

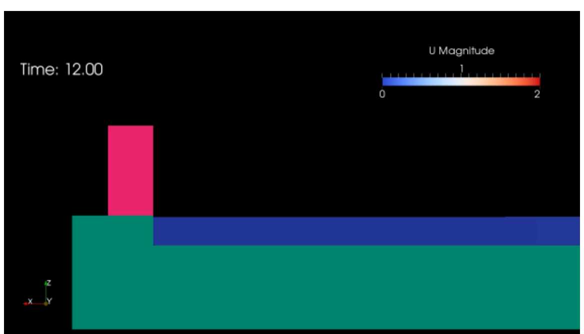
Solitary Wave Test



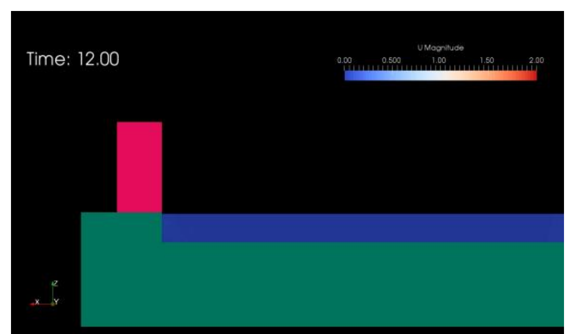
Laminar Simulation



k-ε Simulation

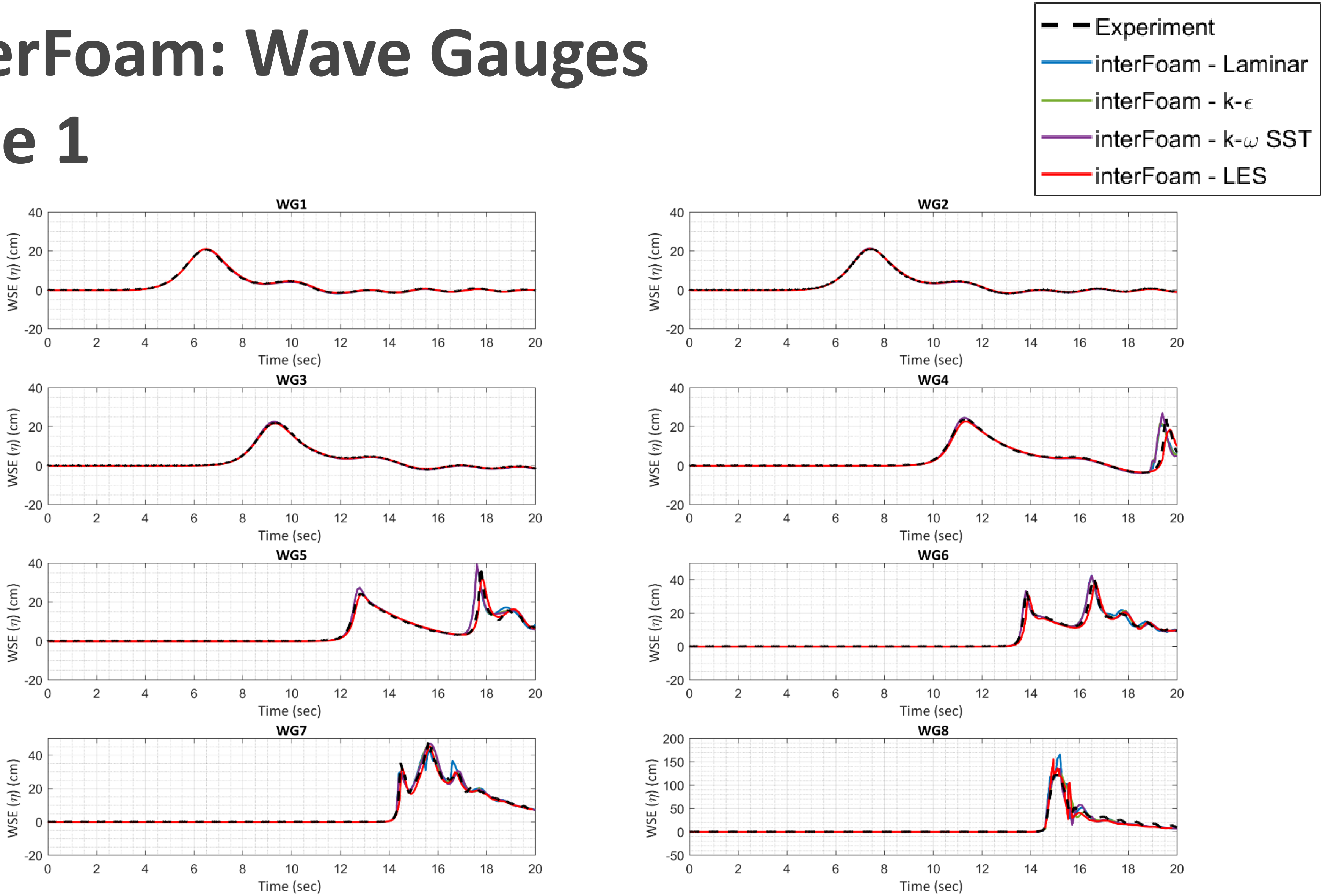


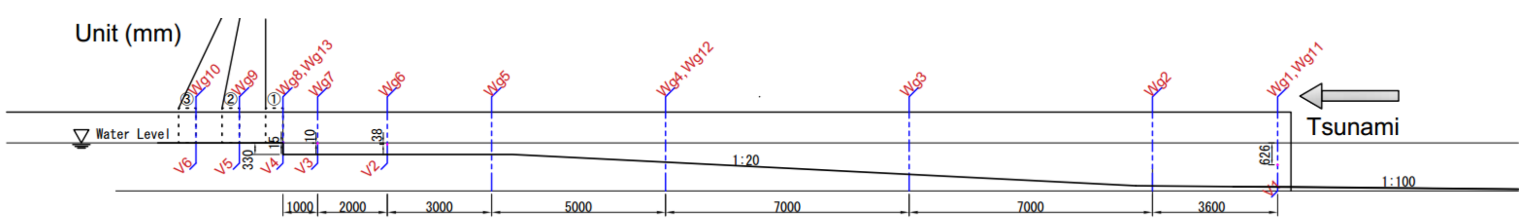
k-ω SST Simulation



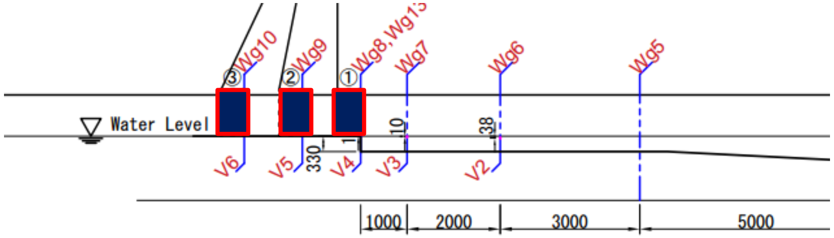
LES

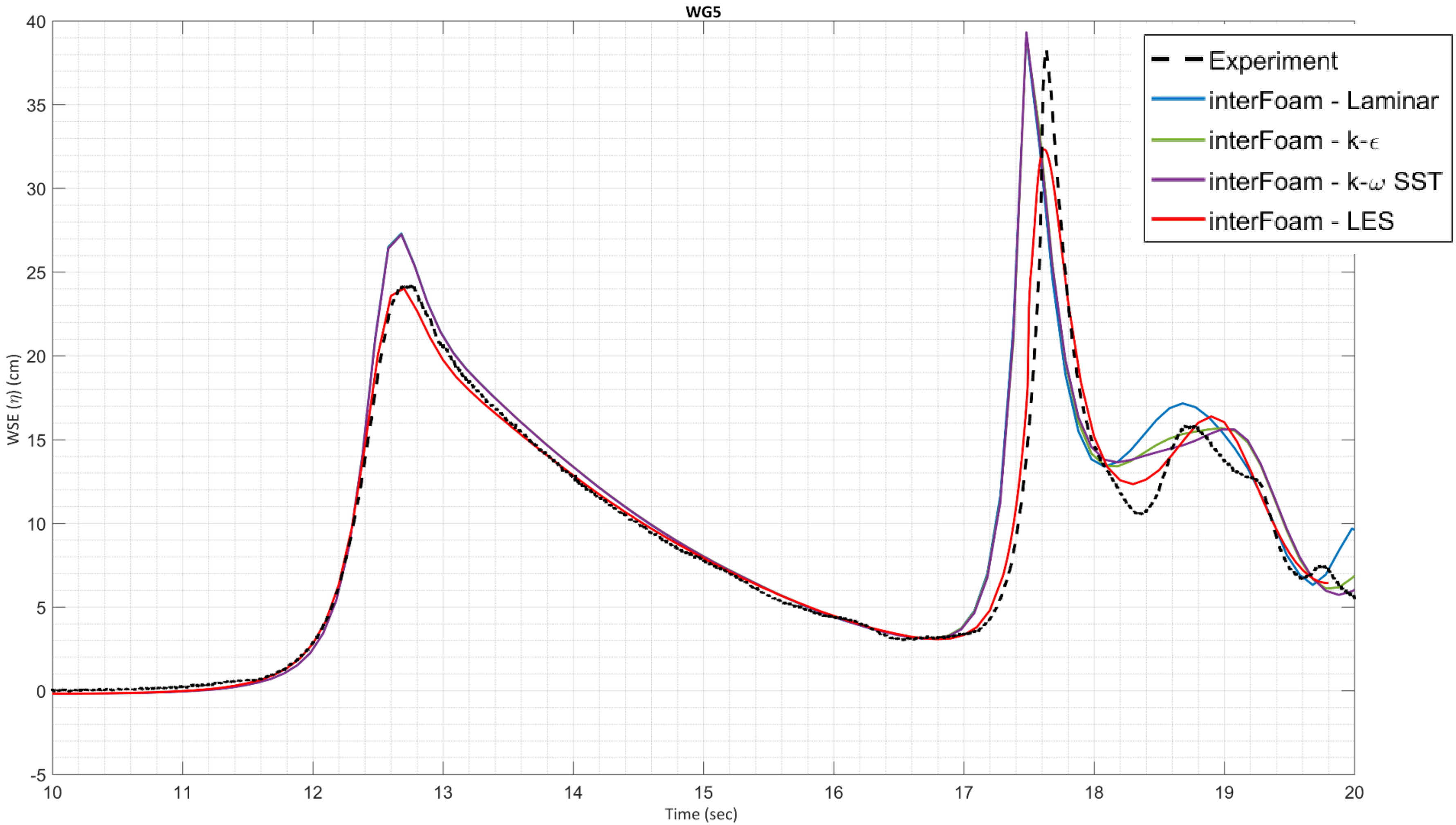
interFoam: Wave Gauges Case 1



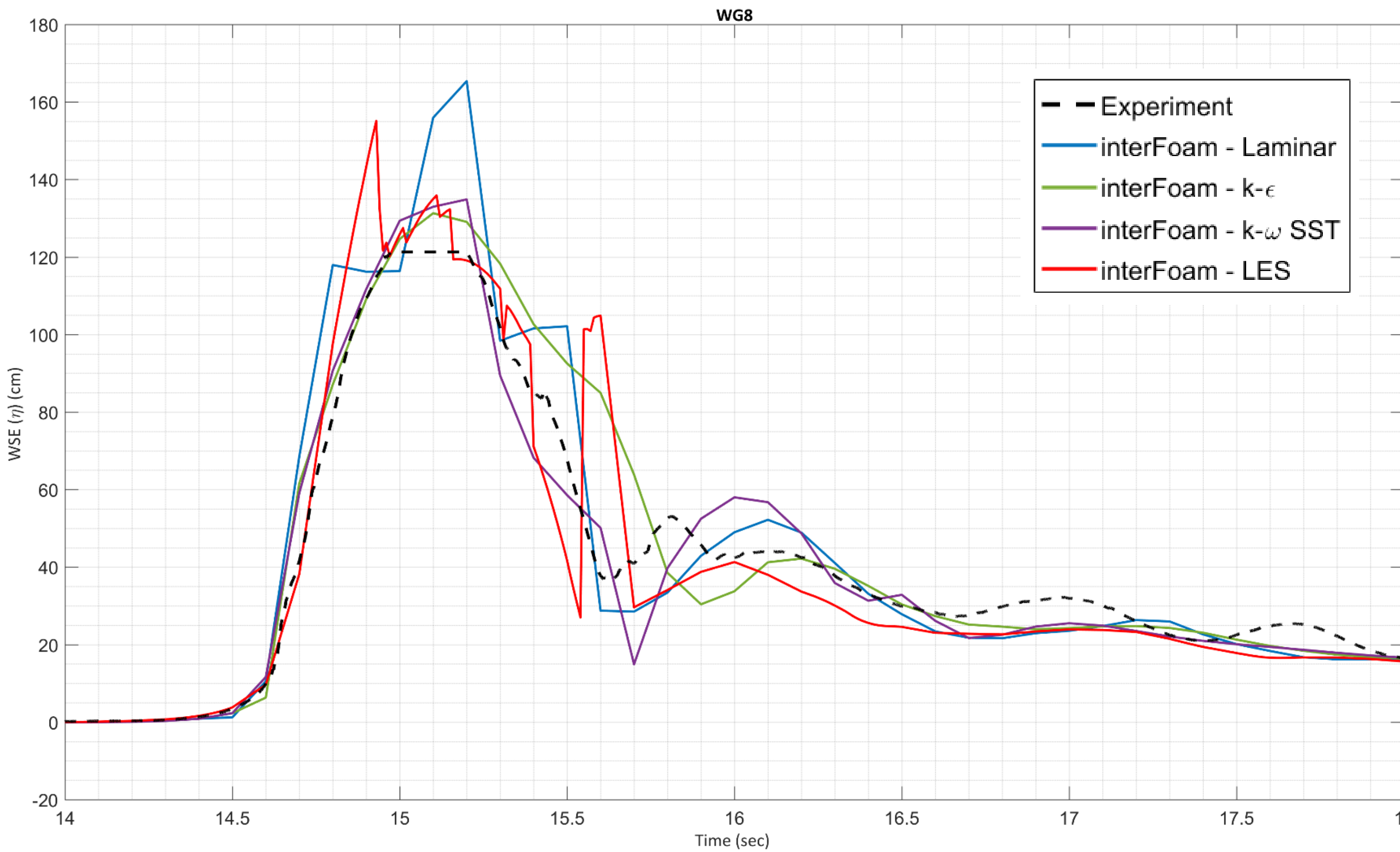


interFoam: WG5
Case 1

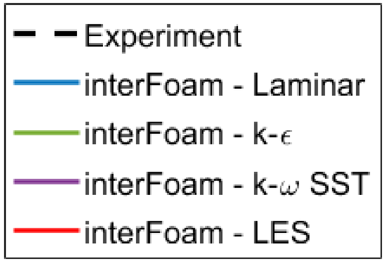


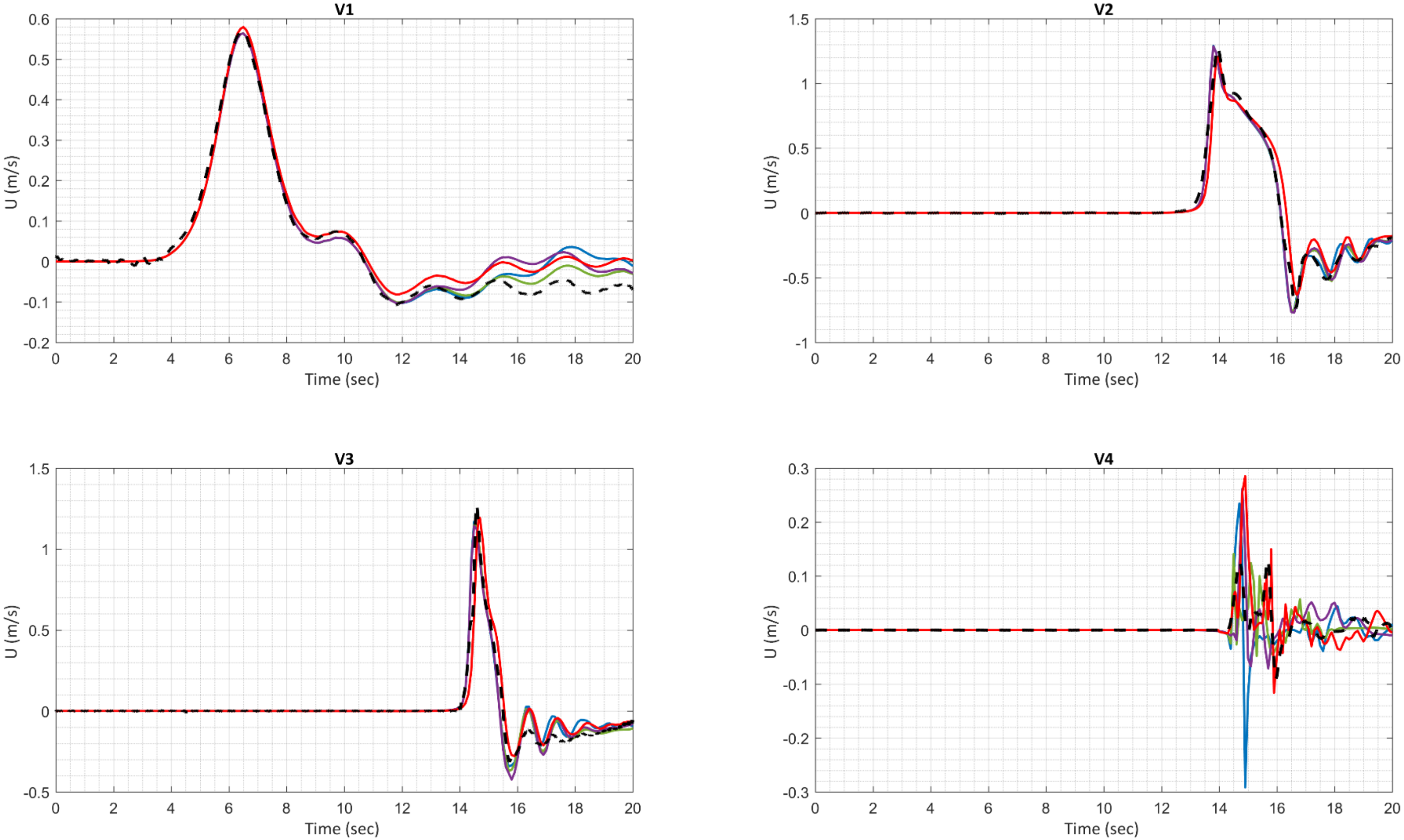


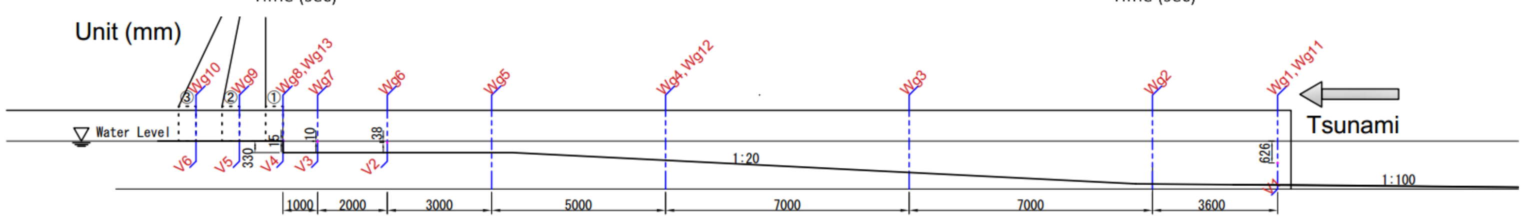
interFoam: WG8
Case 1



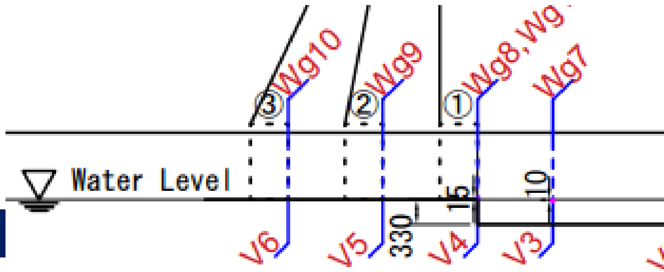
interFoam: Velocimeters Case 1

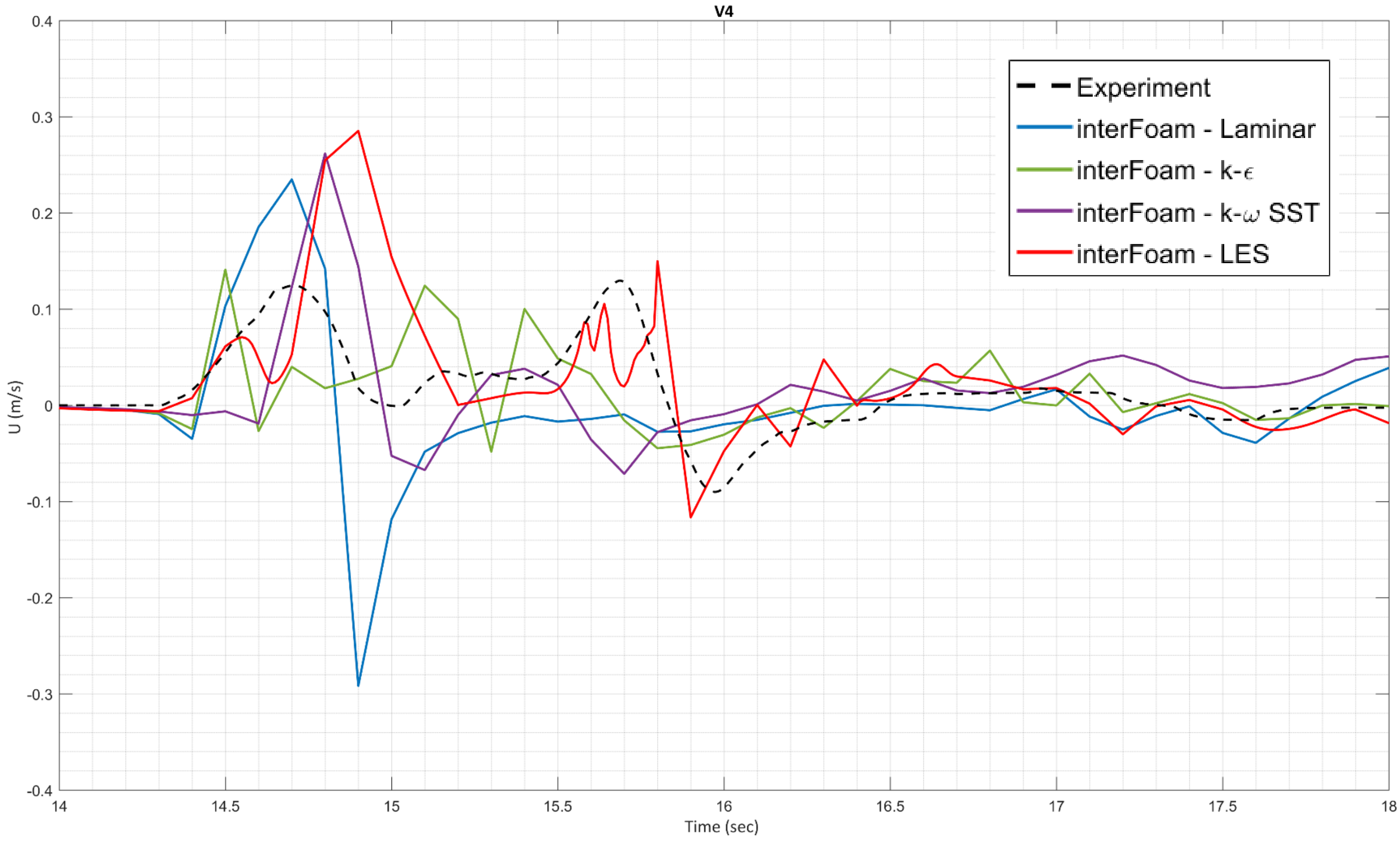




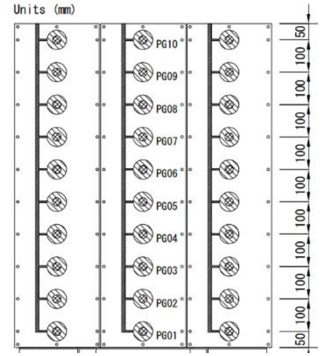


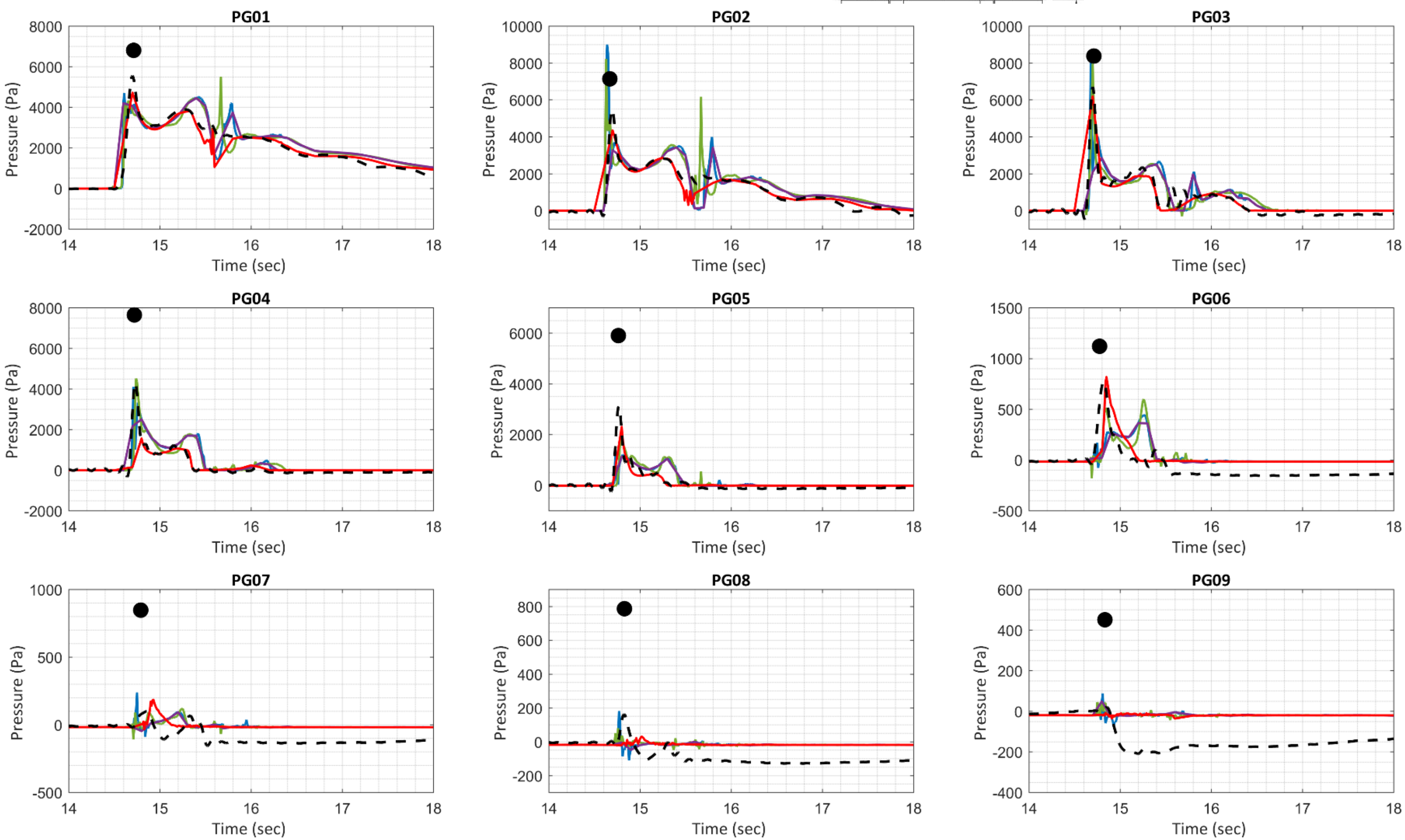
interFoam: V4
Case 1



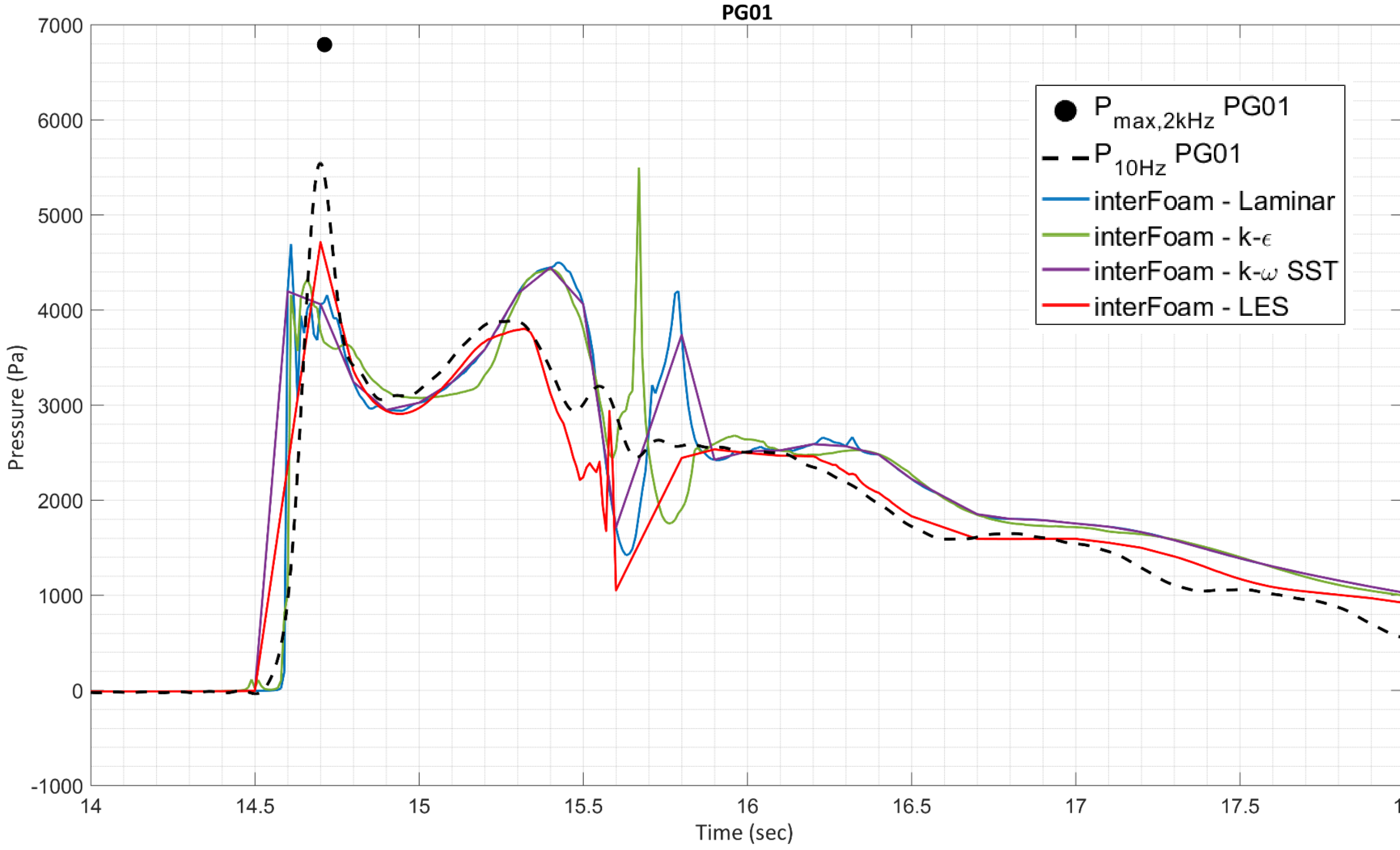


interFoam: Pressure Gauges Case 1





interFoam: PG01
Case 1

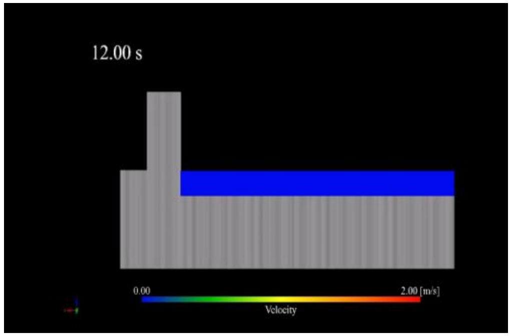


Comparison of Physical Model Experiment and Numerical Model Simulations

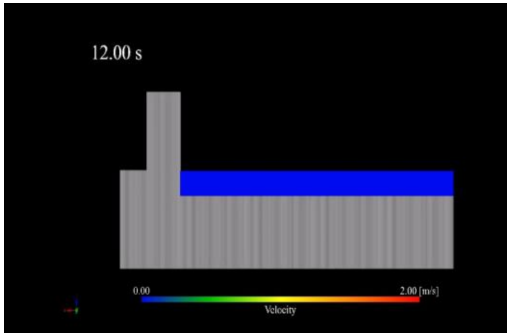
CADMAS-SURF/3D

Case 1

Solitary Wave Test

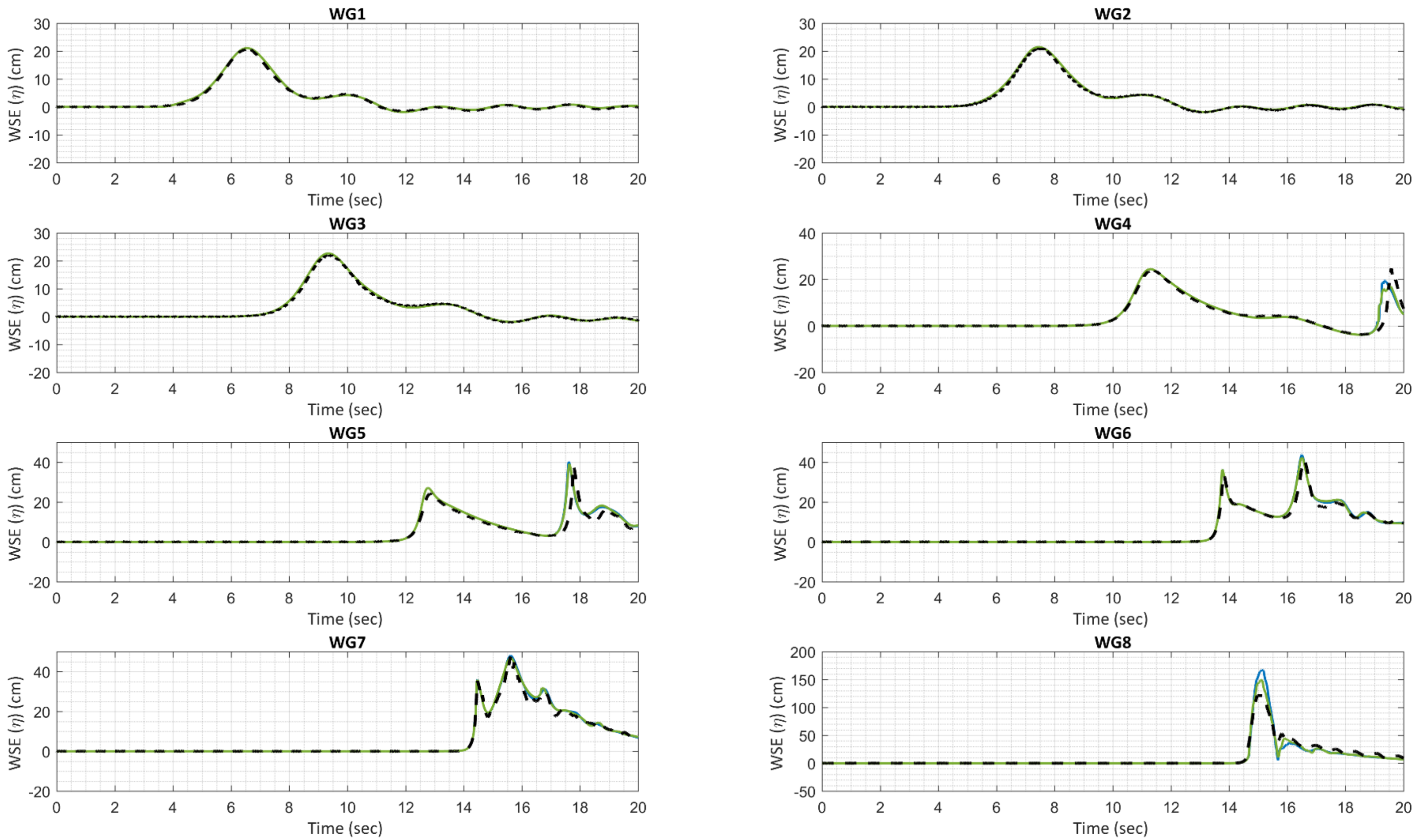


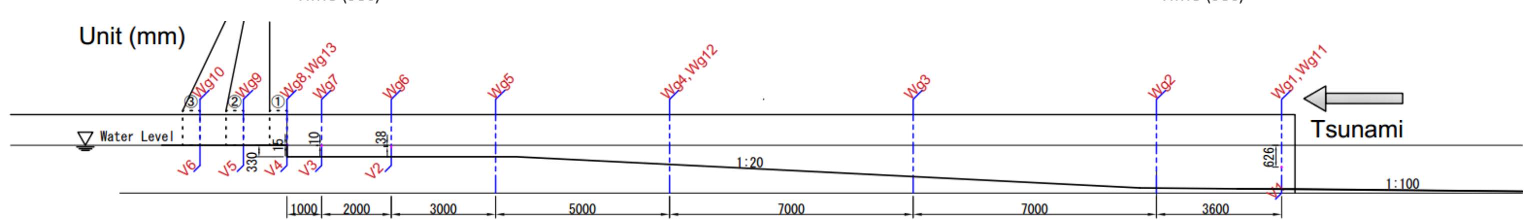
Laminar Simulation



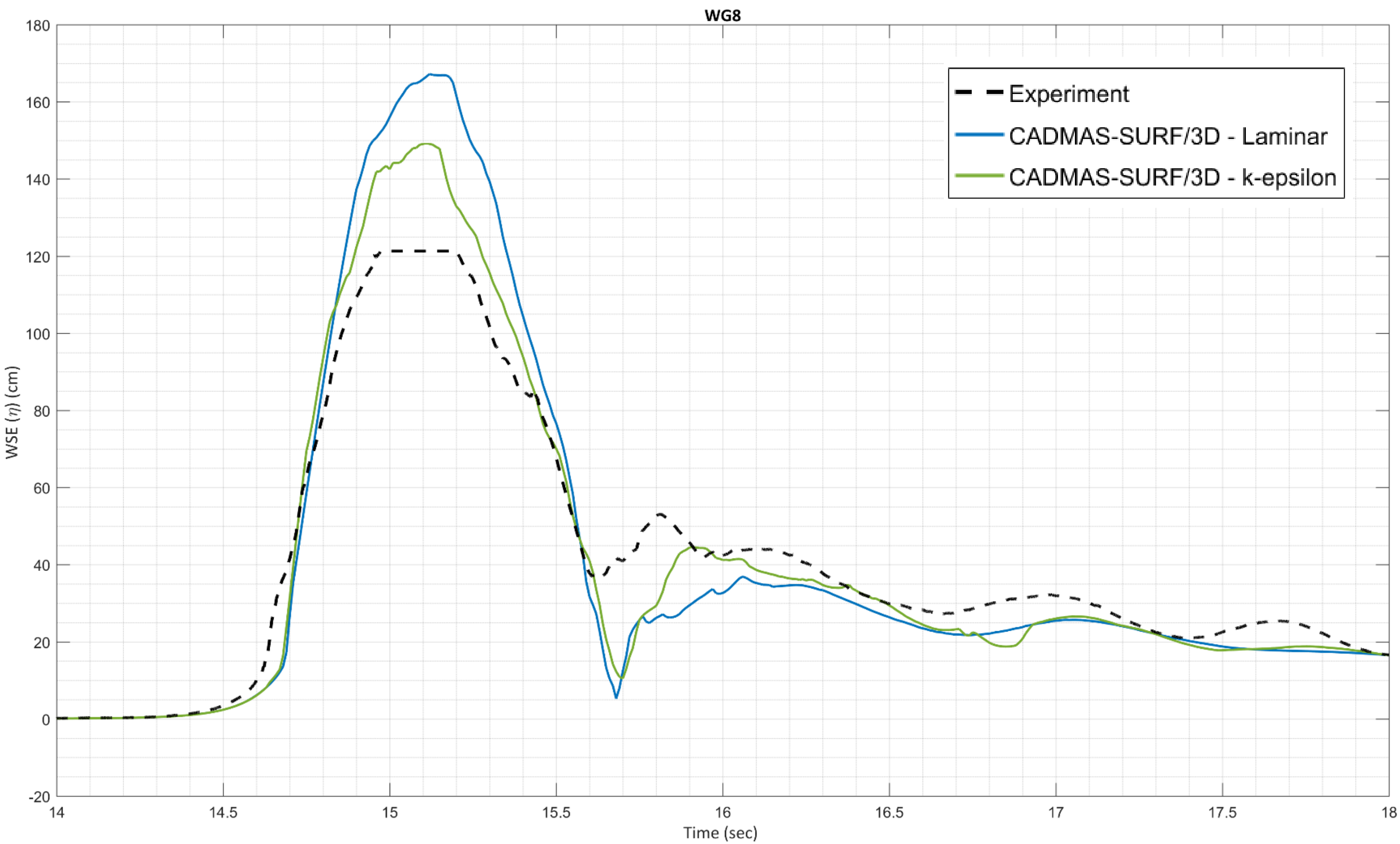
k-ε Simulation

CADMAS-SURF/3D: Wave Gauges Case 1

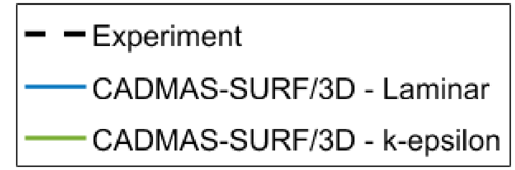


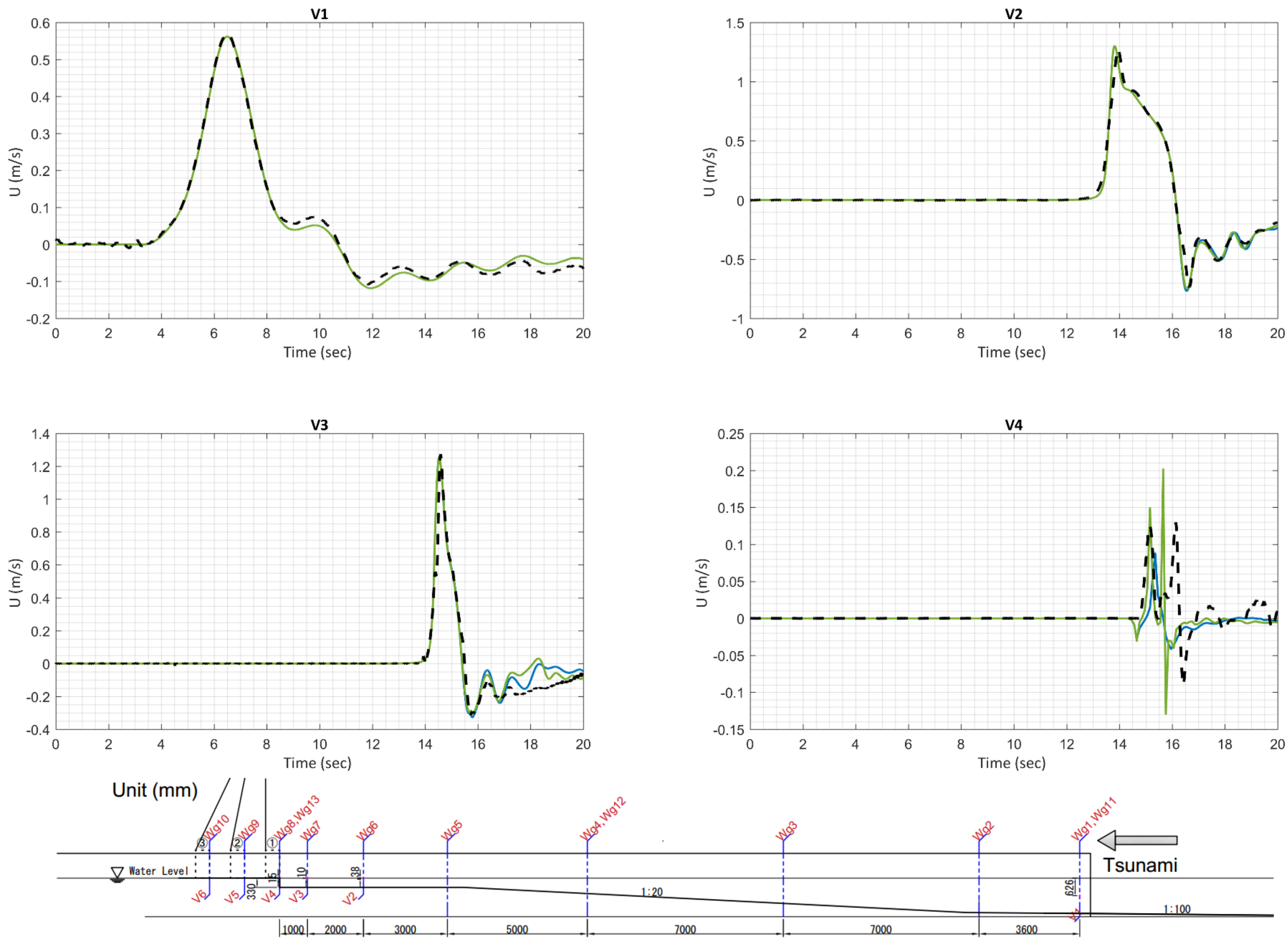


CADMAS-SURF/3D: WG8
Case 1

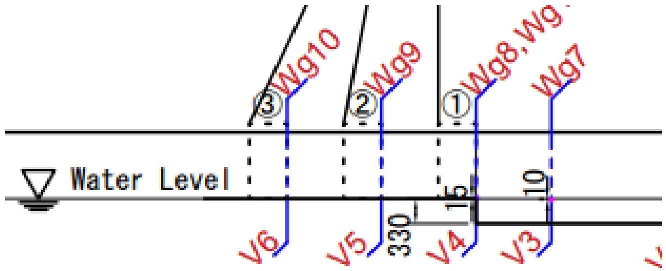


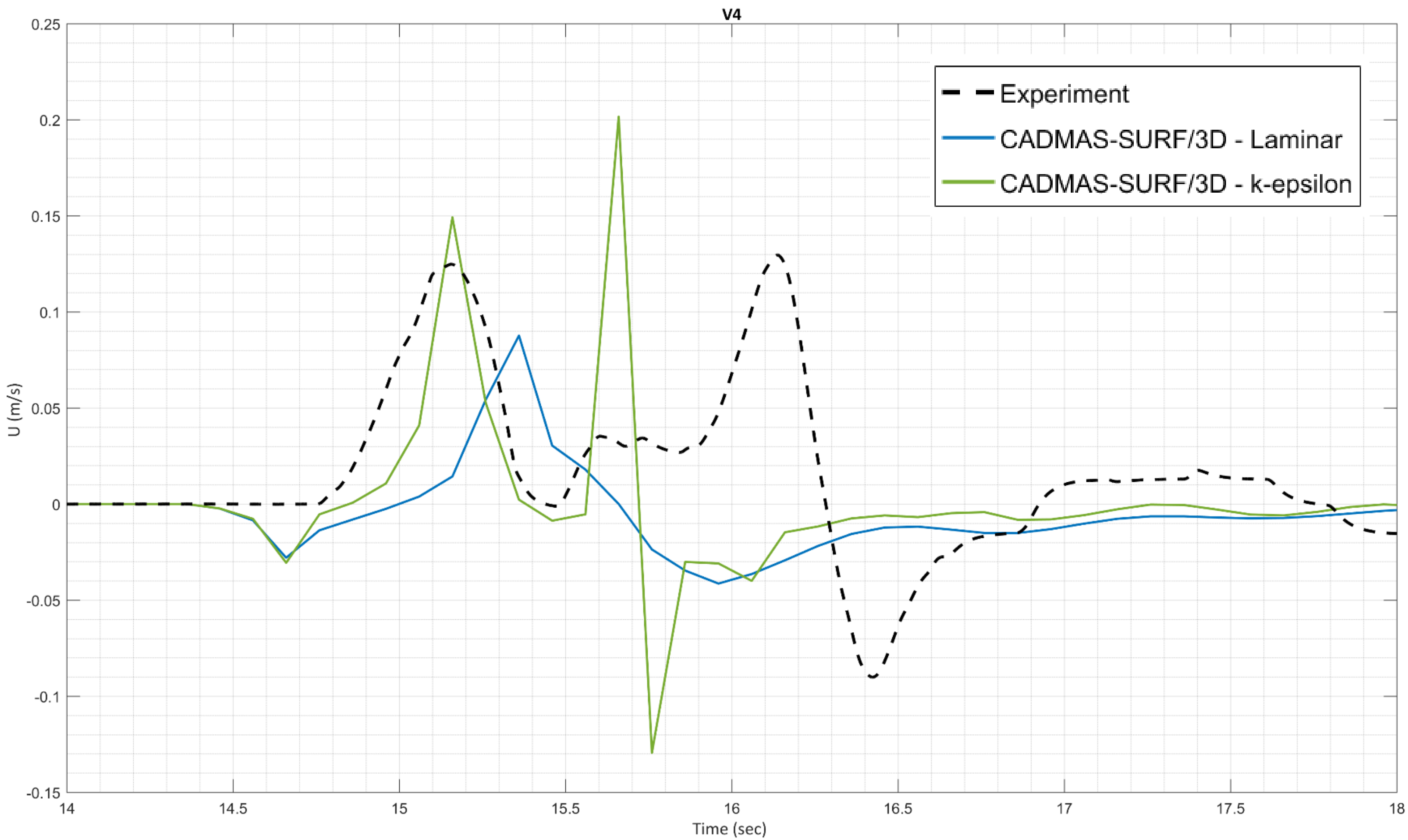
CADMAS-SURF/3D: Velocimeters Case 1



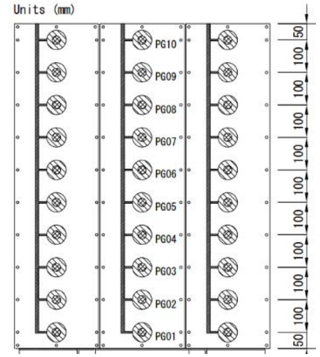


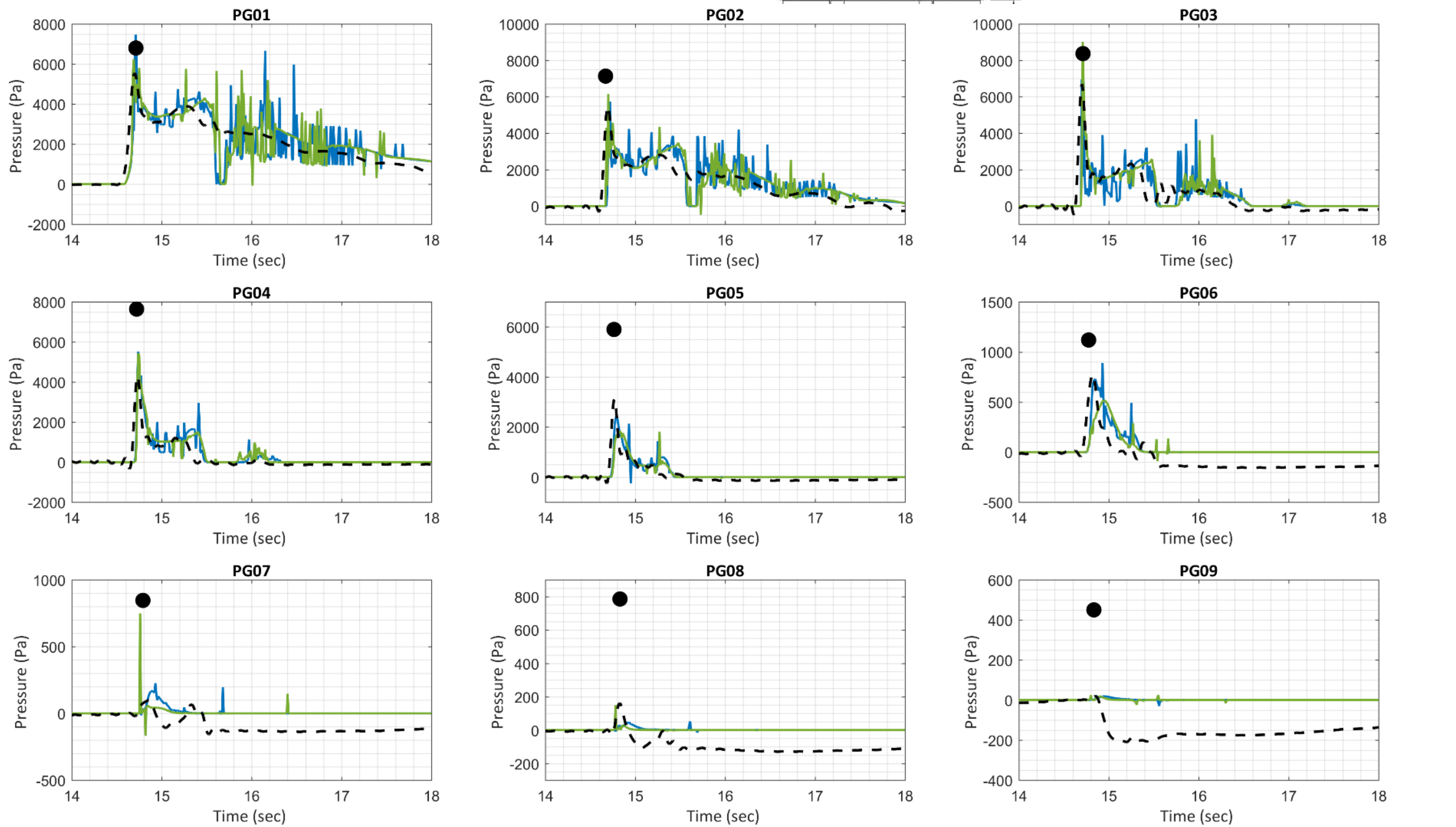
CADMAS-SURF/3D: V4
Case 1



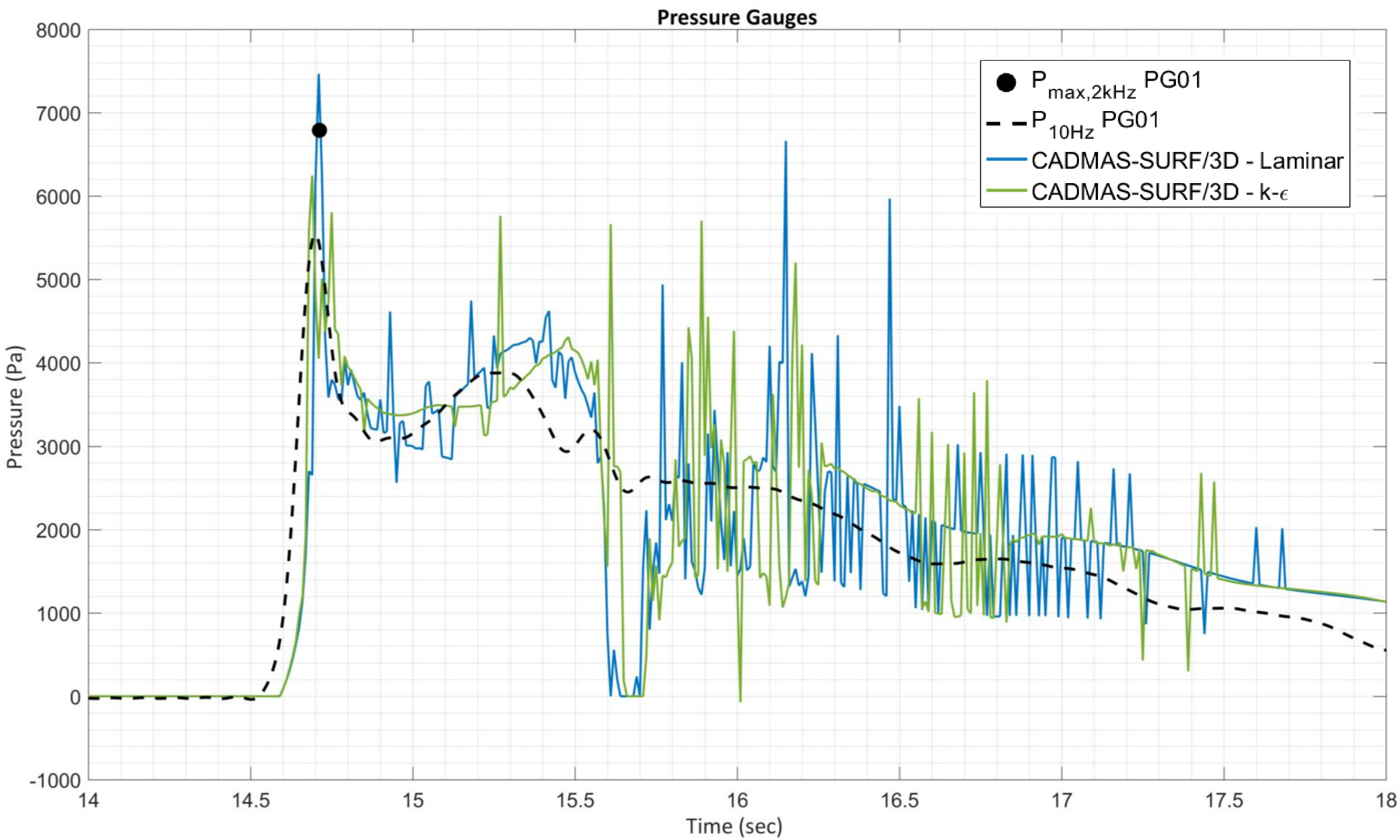


CADMAS-SURF/3D: Pressure Gauges - Case 1





CADMAS-SURF/3D: PG01
Case 1



Quantification of Errors: Wave Gauges

interFoam

Wave Gauges	Case 1			
	Laminar	k-ε	k-ω SST	LES
	Percent Error	Percent Error	Percent Error	Percent Error
WG1	1.85	1.85	1.85	2.44
WG2	1.62	1.62	1.57	0.43
WG3	2.36	2.31	2.27	1.99
WG4	3.67	3.59	3.50	4.56
WG5	12.76	12.55	12.47	0.83
WG6	1.31	1.22	1.19	9.10
WG7	14.26	17.93	16.44	8.43
WG8	8.82	13.62	11.25	2.04

CADMAS-SURF/3D

Wave Gauges	Case 1	
	Laminar	k-ε
	Percent Error	Percent Error
WG1	2.88	2.88
WG2	2.29	2.29
WG3	2.67	2.67
WG4	3.21	3.21
WG5	11.97	11.97
WG6	8.21	8.18
WG7	1.73	1.41
WG8	1.00	1.84

Quantification of Errors: Velocimeters

interFoam

Case 1				
Wave Gauges	Laminar	k-ε	k-ω SST	LES
	Percent Error	Percent Error	Percent Error	Percent Error
V1	0.74	0.69	0.72	2.04
V2	1.26	1.02	0.94	5.49
V3	8.02	9.51	10.14	6.05
V4	88.21	13.07	109.86	128.71

CADMAS-SURF/3D

Case 1		
Wave Gauges	Laminar	k-ε
	Percent Error	Percent Error
V1	1.00	1.00
V2	2.20	2.20
V3	1.18	1.18
V4	29.73	19.65

Quantification of Errors: Pressure Gauges

interFoam

Wave Gauges	Case 1 Laminar	k-ε	k-ω SST	LES
	Percent Error	Percent Error	Percent Error	Percent Error
PG01	30.89	38.77	38.22	30.59
PG02	26.07	15.03	54.24	39.15
PG03	1.94	4.97	66.06	26.14
PG04	46.38	40.94	67.26	79.61
PG05	76.79	69.01	80.87	61.01
PG06	84.86	54.09	76.05	26.99
PG07	71.83	89.37	89.14	78.23
PG08	74.49	87.40	98.23	96.34
PG09	76.00	85.82	84.81	97.54

CADMAS-SURF/3D

Wave Gauges	Case 1 Laminar	k-ε
	Percent Error	Percent Error
PG01	9.96	7.99
PG02	19.68	13.77
PG03	16.82	7.81
PG04	27.83	28.89
PG05	58.26	69.22
PG06	34.65	53.72
PG07	75.67	11.41
PG08	96.27	81.02
PG09	94.87	94.31

Overall Conclusions

- Water surface elevation and particle velocities can be captured in reasonably well agreement with the experimental results.
- Although quasi-static pressure distribution can be captured, impact pressure could not be captured accurate enough in the numerical simulations.
- Both two numerical models performed well along the channel away from the vertical wall.
- Significant deviations from the experimental results start with breaking near the vertical wall.
- CADMAS-SURF/3D performed better near the vertical wall.
  - Single phase vs multiphase solution (?)
  - Local mesh refinement (?) to improve the results of interFoam
- Computational Time:
  - CADMAS-SURF/3D is faster than interFoam (about 2 times!)
  - LES took the longest computational duration.

Conclusions on Turbulence Modeling

Considering the present mesh configuration:

- Use of turbulence modeling approaches improve the results as the breaking processes involved more *as expected.*
- interFoam
  - k-ε turbulence model is much dissipative than the k-ω-SST model
  - LES mostly improved the results; however, it gave worse results in several gauges near the vertical wall
    - Local mesh refinement (?)
- CADMAS-SURF/3D
  - Although k-ε turbulence model did not improve the results significantly in scope of wave gauges and velocimeters, it significantly improved pressure calculations.

Future Work

- 3D simulations with two equation models → to eliminate 2D/3D effects
- Local mesh refinement in front of the wall
- New turbulence modeling approaches!
  - Larsen and Fuhrman (2018) “On the over-production of turbulence beneath surface waves in RANS models”, Accepted for publication in JFM
  - In ICCE18: Friday, 8.30, Grand Ballroom III & IV

Thank you for your kind attention.