Floating and berm breakwaters

Projects, innovation and a call for research

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Norconsult

Personal Summary

- Bachelor of Engineering: Harbour Engineering and Offshore Technology, AMET University, India – 2012
- Junior Maritime Engineer at Howe Engineering (2012-2014)
- MSc, COMEM (Coastal and Marine Eng and Management) (TUDelft / NTNU) – 2016
- Research Assistant at NTNU, Trondheim – 2016
- Coastal Engineer at Norconsult AS, Trondheim (2017 – Present)

Contents

- **Research on porous structures at NTNU**
  - Use of numerical tool along with physical models in design of porous breakwaters
  - CFD simulation of wave interaction with porous structures
  - Validating numerical model for Dam break, porous abutment and a rubble mound breakwater
  - Study on wave kinematics inside berm breakwaters

- **Floating breakwater project at Norconsult**
  - Marina solutions had installed floating breakwaters at Molde
  - Measure waves inside and outside the basin
  - Calculate the damping coefficient of the floating breakwater

Design of porous coastal structures

- **Semi empirical formulations**

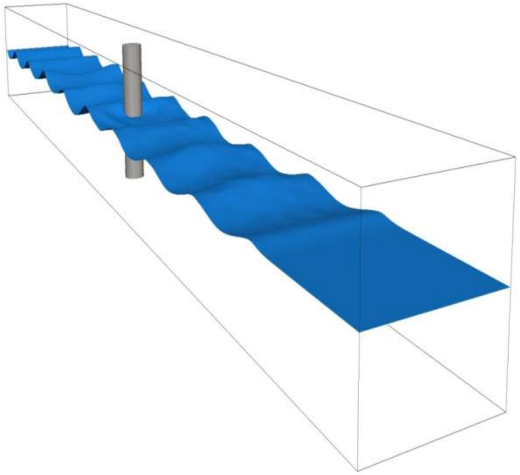
- Provide the design in a simple and fast way.
- Based on adjusted dimensional analysis of sets of laboratory experiments.
- Van der Meer (1987) for rubble-mound breakwater.
- Very fast and inexpensive method.
- Not strictly applicable outside the conditions that they were derived for.
- Not applicable to design structures with non conventional sections or with important local effects.

- **Physical modelling**
- Reduces the uncertainty when obtaining the structural response
- Intrusive measuring devices, scale effects, high cost (in time and money) of the experiments.

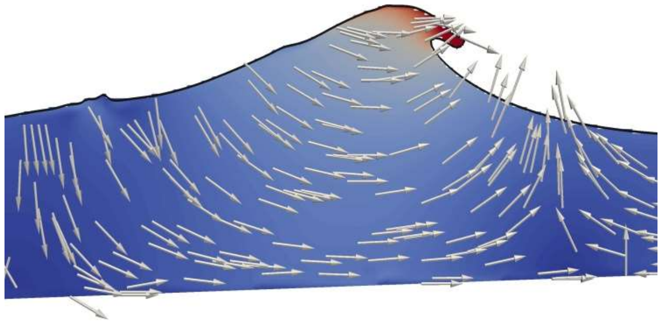
- **Physical modelling + Numerical modelling**
- Use of numerical modelling as a complementary tool to physical modelling.
- Assisting with the pre-design of the physical models.
- Extending the experimental database with detailed results, after validation

REEF3D

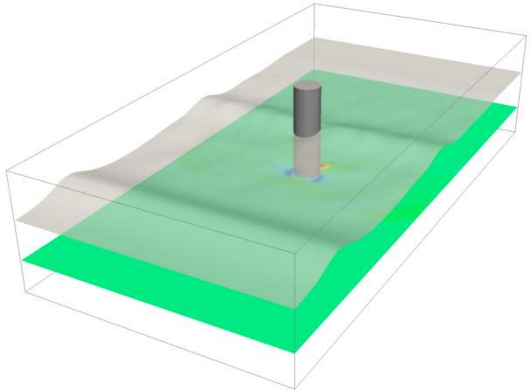
- Based on Reynolds Averaged Navier Stokes (RANS) equations
- Level set method for Interface and free surface capture
- Numerical wave tank with number of wave generation and absorption methods
- Successfully used for a range of marine applications, such as breaking wave forces, floating body dynamics, sediment transport and sloshing.



Single Cylinder



Breaking Waves



Local scour

Source : https://reef3d.wordpress.com/

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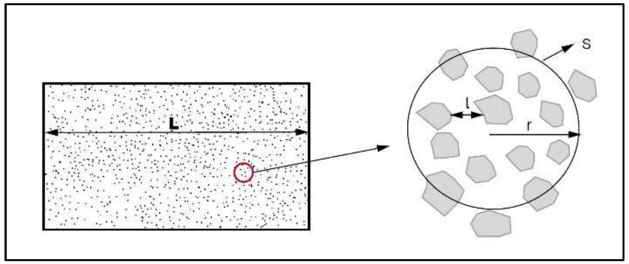
VRANS

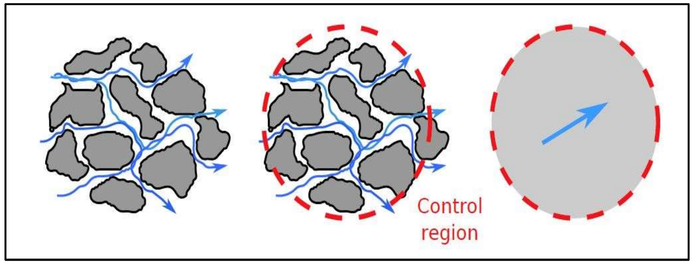
RANS equation

$$\frac{\partial u_i}{\partial x_i} = 0$$

$$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\nu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\right] + g_i$$

Volume averaged





VRANS equations

$$F_i = -a\rho\langle\overline{u_i}\rangle - b\rho\sqrt{\langle\overline{u_j}\rangle\langle\overline{u_j}\rangle}\langle\overline{u_i}\rangle$$

$$a = \alpha\frac{(1-n)^2}{n^3}\frac{\nu}{\rho d_{50}^2}$$

$$b = \beta\left(1 + \frac{7.5}{KC}\right)\frac{(1-n)}{n^3}\frac{1}{d_{50}}$$

- *F_i represents the effect of turbulence in terms of additional resistance. This is modelled using the extended Darcy-Forcheimmer equation*
- *a and b are Resistance coefficients*
- *α and β have to be determined experimentally.*
- ❖ *Reynolds number*
- ❖ *Shape of the stones*
- ❖ *Permeability*
- ❖ *Grade of porous material.*

Jensen, B., Jacobsen, N., and Christensen, E., 2014. "Investigations on the porous media equations and resistance coefficients for coastal structures.". . Coastal Engineering, 84, pp. 56–72.

Validation of VRANS for wave interaction with porous structures

- Dam break with crushed rock and glass beads

❖ *Liu, P., Lin, P., Chang, K., and Sakakiyama, T., 1999. "Numerical modeling of wave interaction with porous structures.". J. Waterw. Port Coast. Ocean Eng., 125, pp. 322– 330.*

- Solitary and regular wave interaction with porous abutment

❖ *Lara, J.L.and del Jesus, M.; Losada, I. Three-dimensional interaction of waves and porous structures, Coastal Engineering 2012, 64, 24–46.*

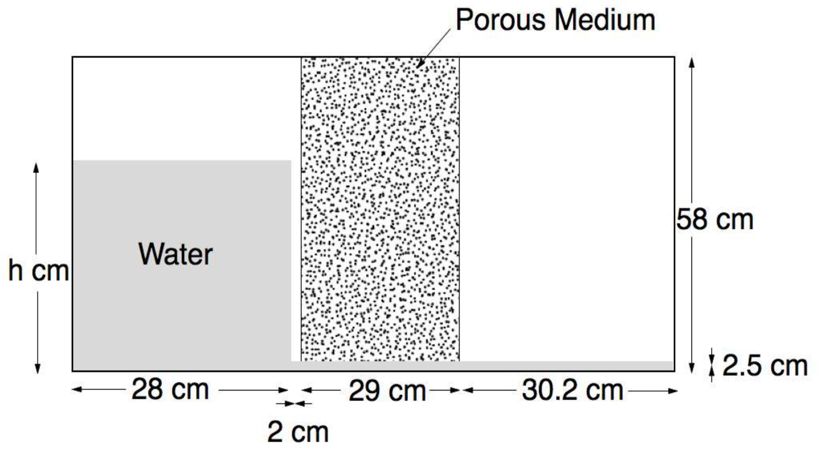
- Regular wave interaction with rubble mound breakwater

❖ *Arntsen, Ø. A., I. J. Malmedal, B. Brørs and A. Tørum (2003): Numerical and experimental modelling of pore pressure variation within a rubble mound breakwater. POAC'03 Trondheim, Norway, June 16-19, 2003.*

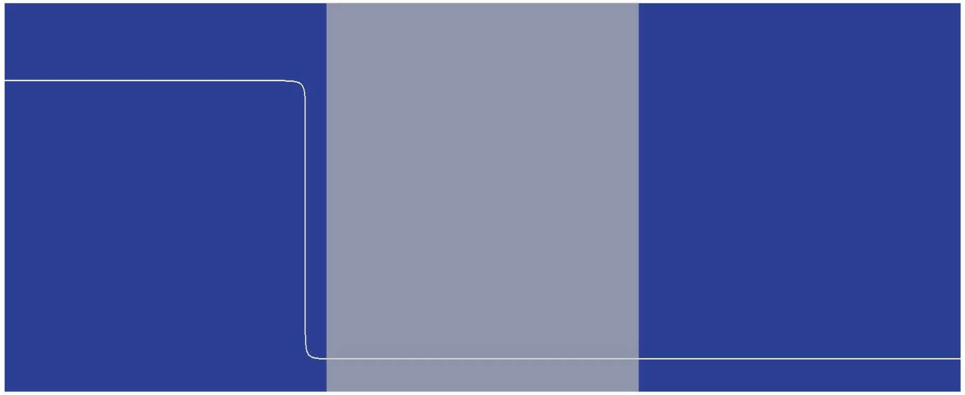
Dam break case

- Tank = 89.2 cm × 44 cm × 58 cm
- Porous medium = 29 cm × 44 cm × 37 cm
- Crushed rock : d_{50} = 0.0159 m, Porosity, n = 0.49
- Glass beads : d_{50} = 0.003 m, Porosity, n = 0.39

Experimental setup



Numerically simulated dam break case in REEF3D



Liu, P., Lin, P., Chang, K., and Sakakiyama, T., 1999. "Numerical modeling of wave interaction with porous structures.". J. Waterw. Port Coast. Ocean Eng., 125, pp. 322– 330.

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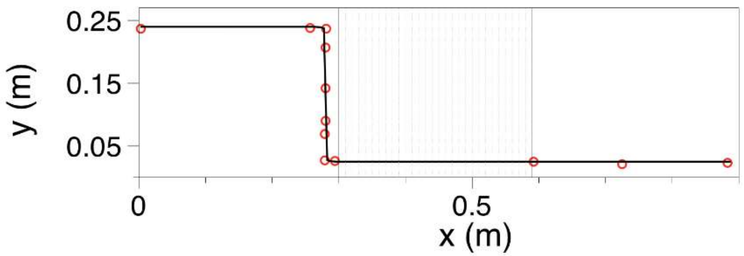
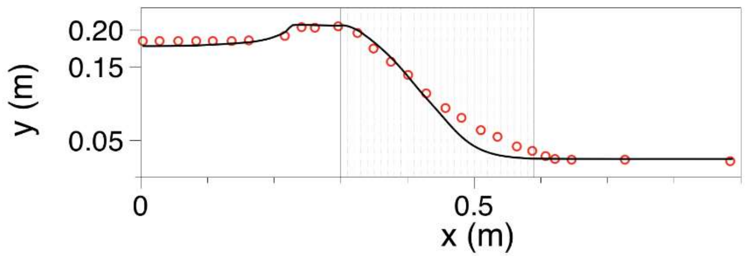
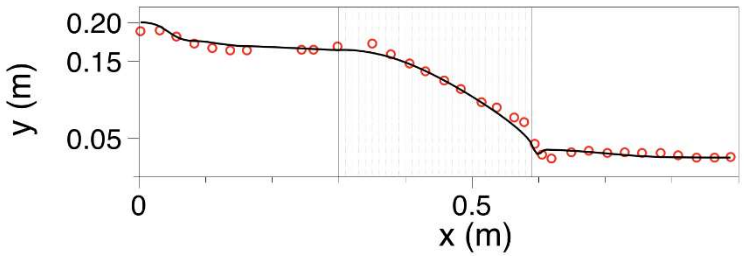
Comparison for crushed rock



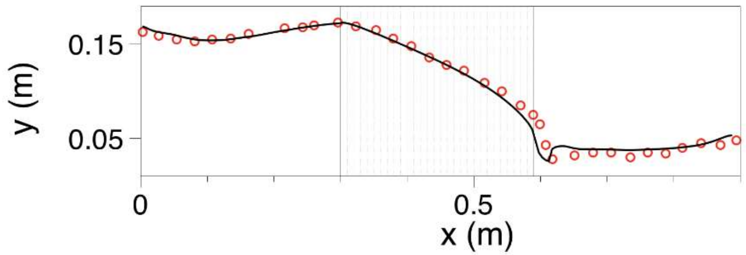
t = 0 s



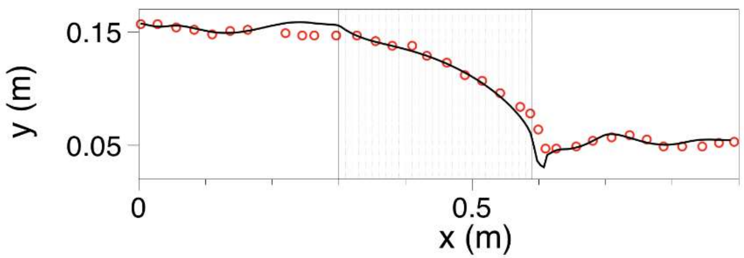
t = 0.4 s



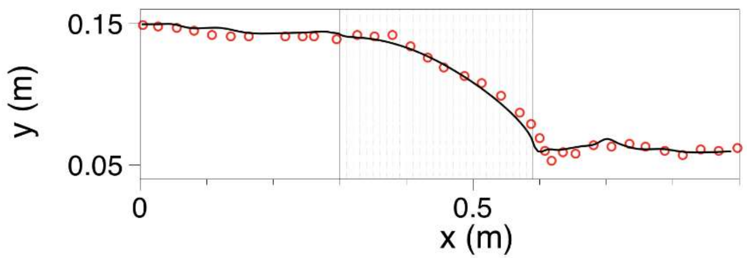
t = 0.8 s



t = 1.2 s

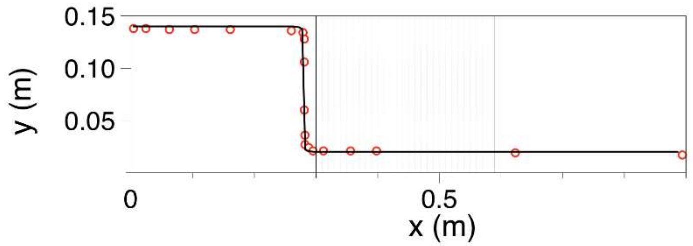


t = 1.6 s

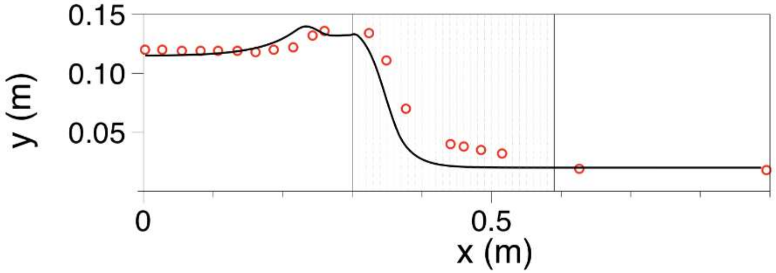


t = 2.0 s

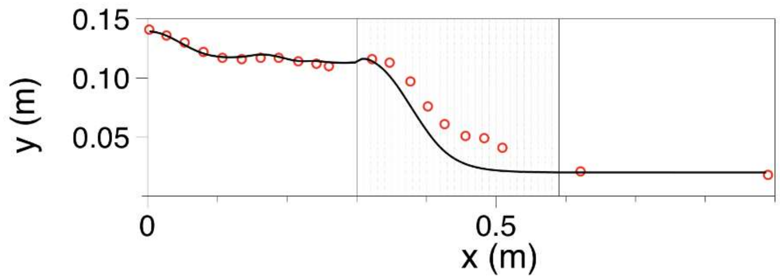
Comparison for glass beads



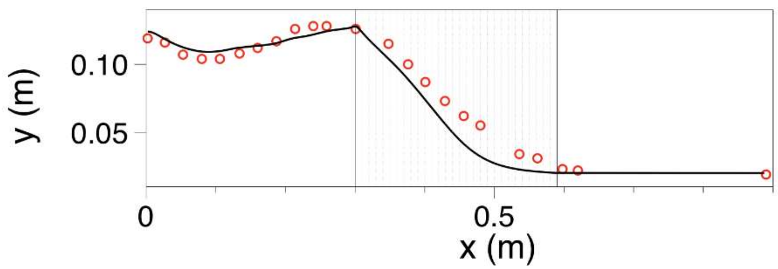
t = 0 s



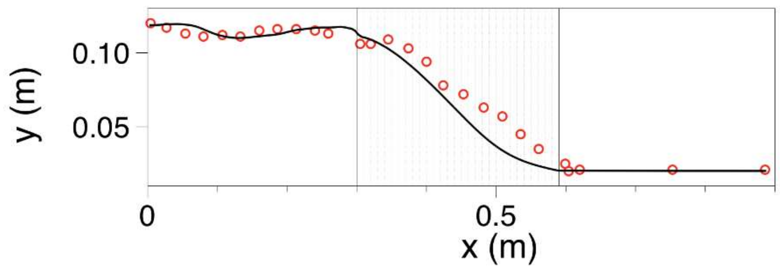
t = 0.4 s



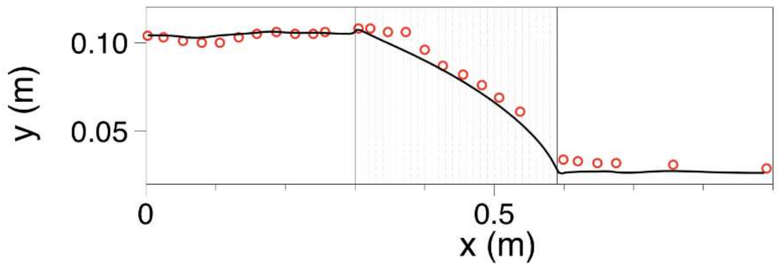
t = 0.8 s



t = 1.2 s



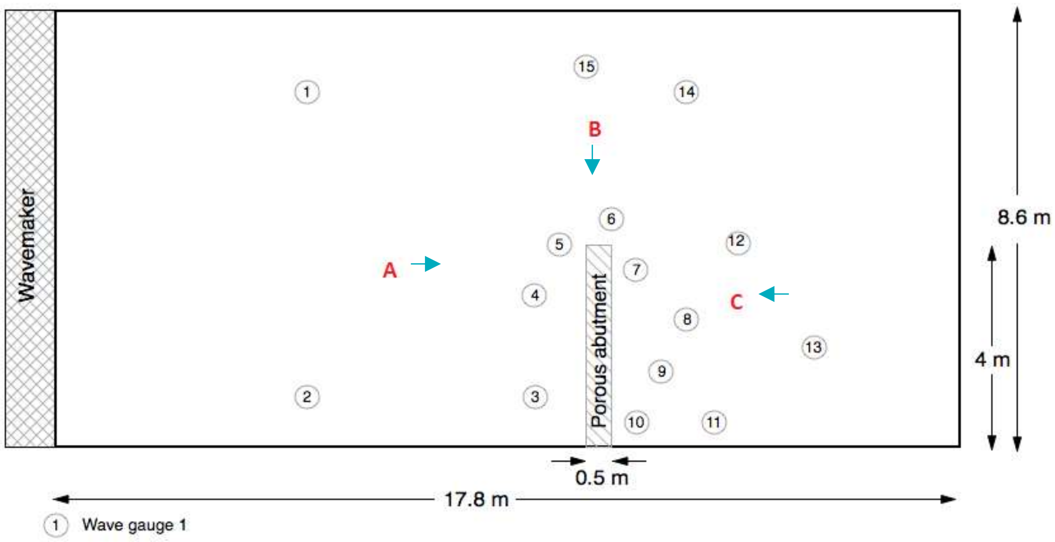
t = 1.6 s

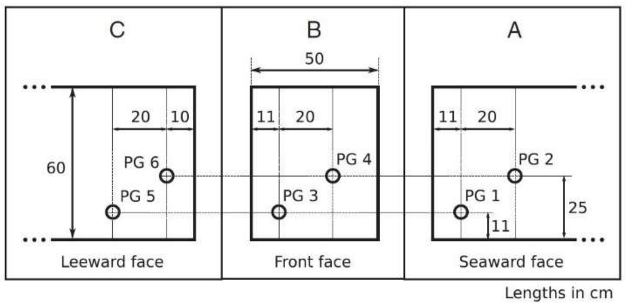


t = 4.0 s

Solitary and regular wave interaction with Porous Abutment

- ❖ NWT : 17.8 m × 8.6 m × 0.65 m
- ❖ Grid size, Δx = 1 cm
- ❖ 15 wave gauges to measure the free surface
- ❖ 6 pressure probes on the abutment face
- ❖ Runs for both solitary and regular waves

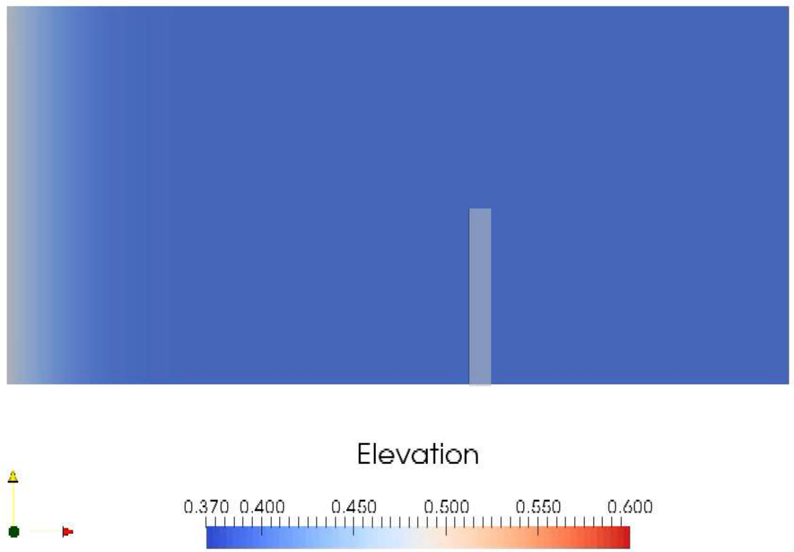




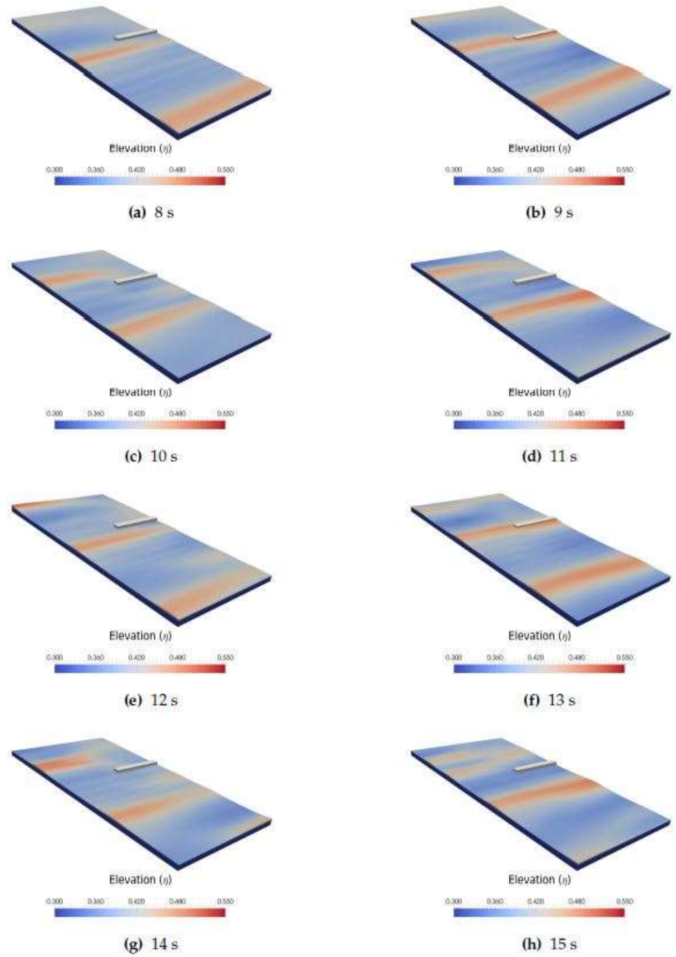
Lara, J.L.and del Jesus, M.; Losada, I. Three-dimensional interaction of waves and porous structures, Coastal Engineering 2012, 64, 24–46.

Numerically simulated wave interaction with porous abutment

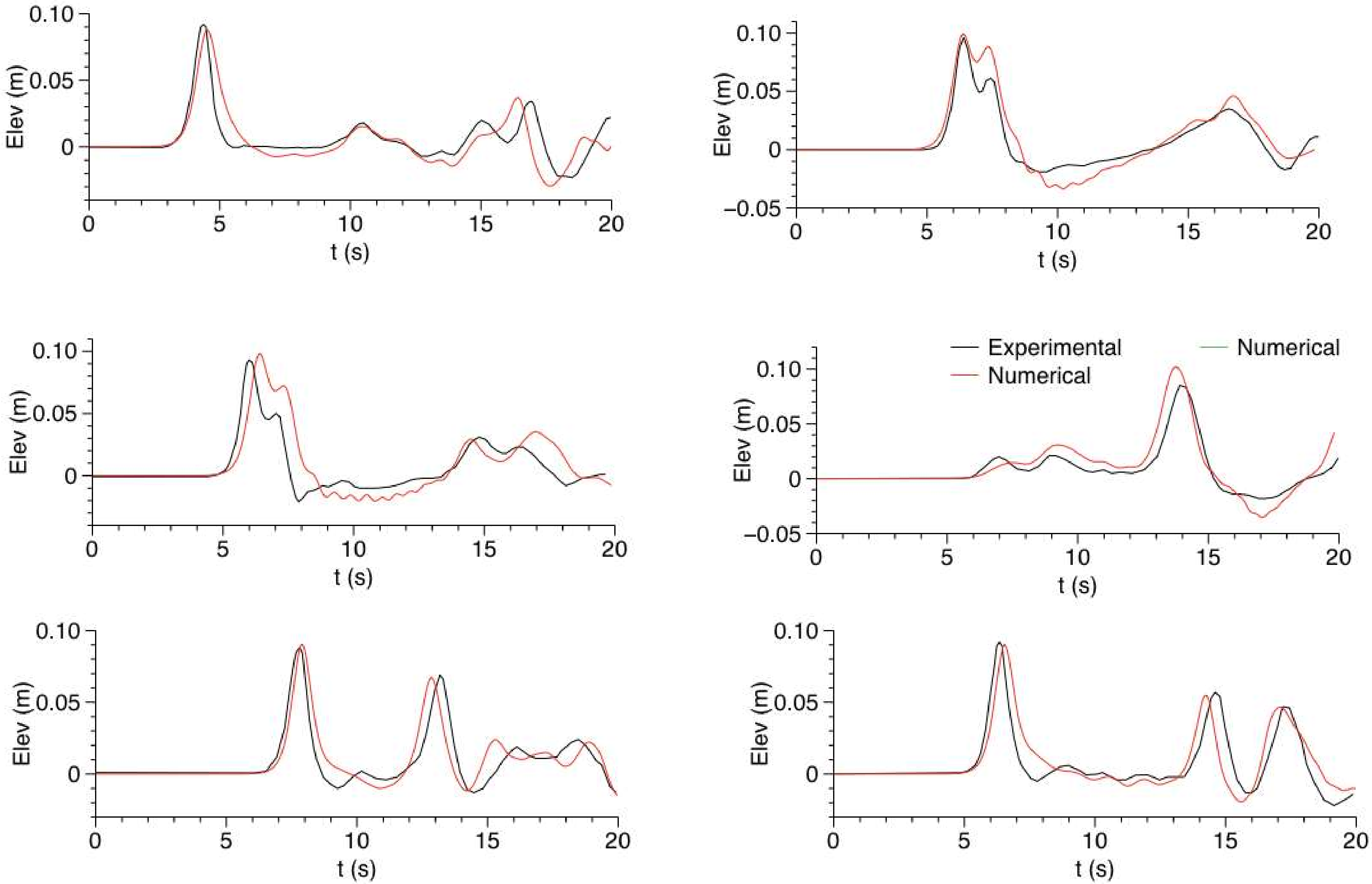
Solitary wave interaction with porous abutment



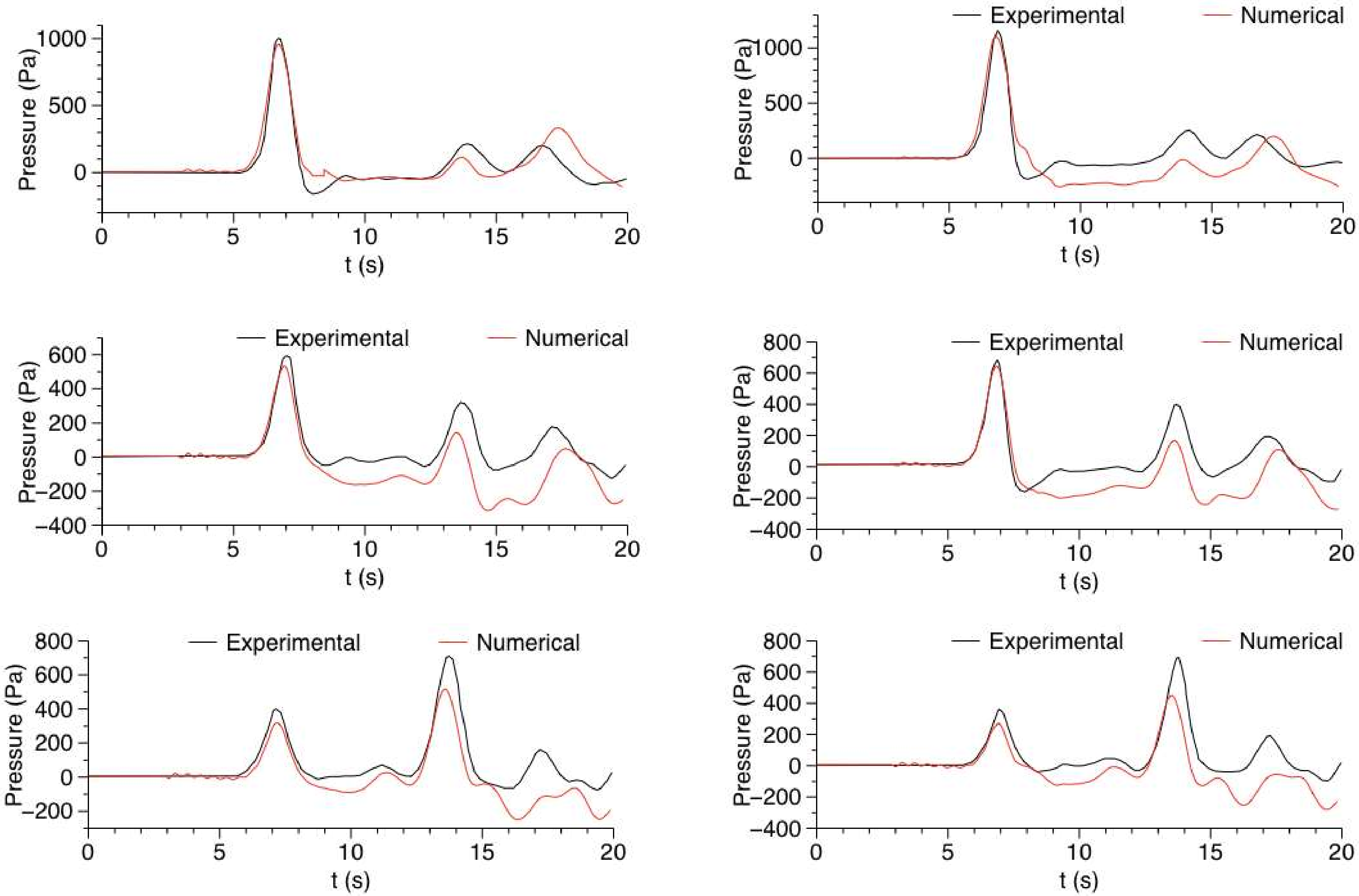
Regular wave interaction with porous abutment



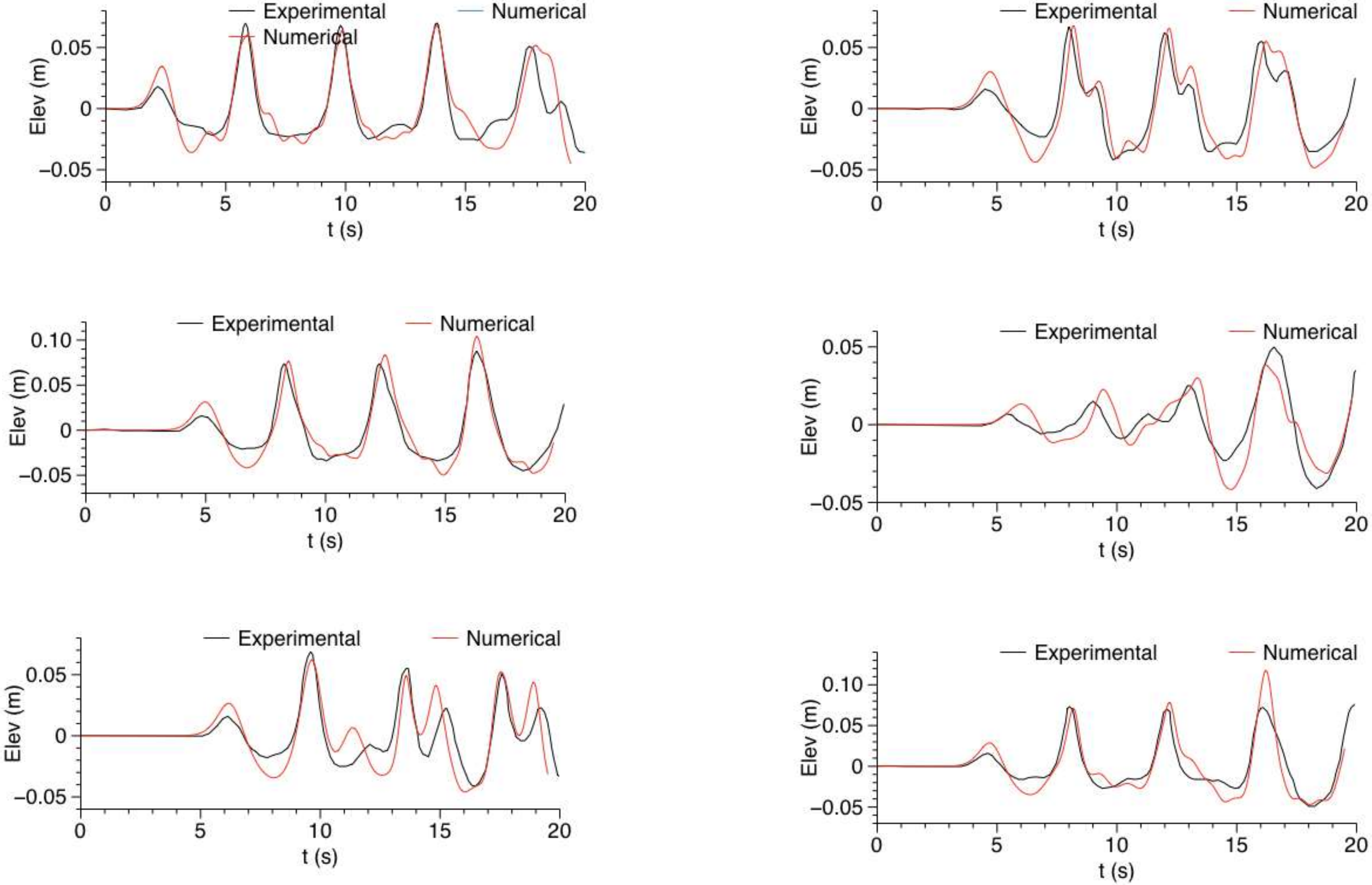
Comparison of free surface for solitary waves



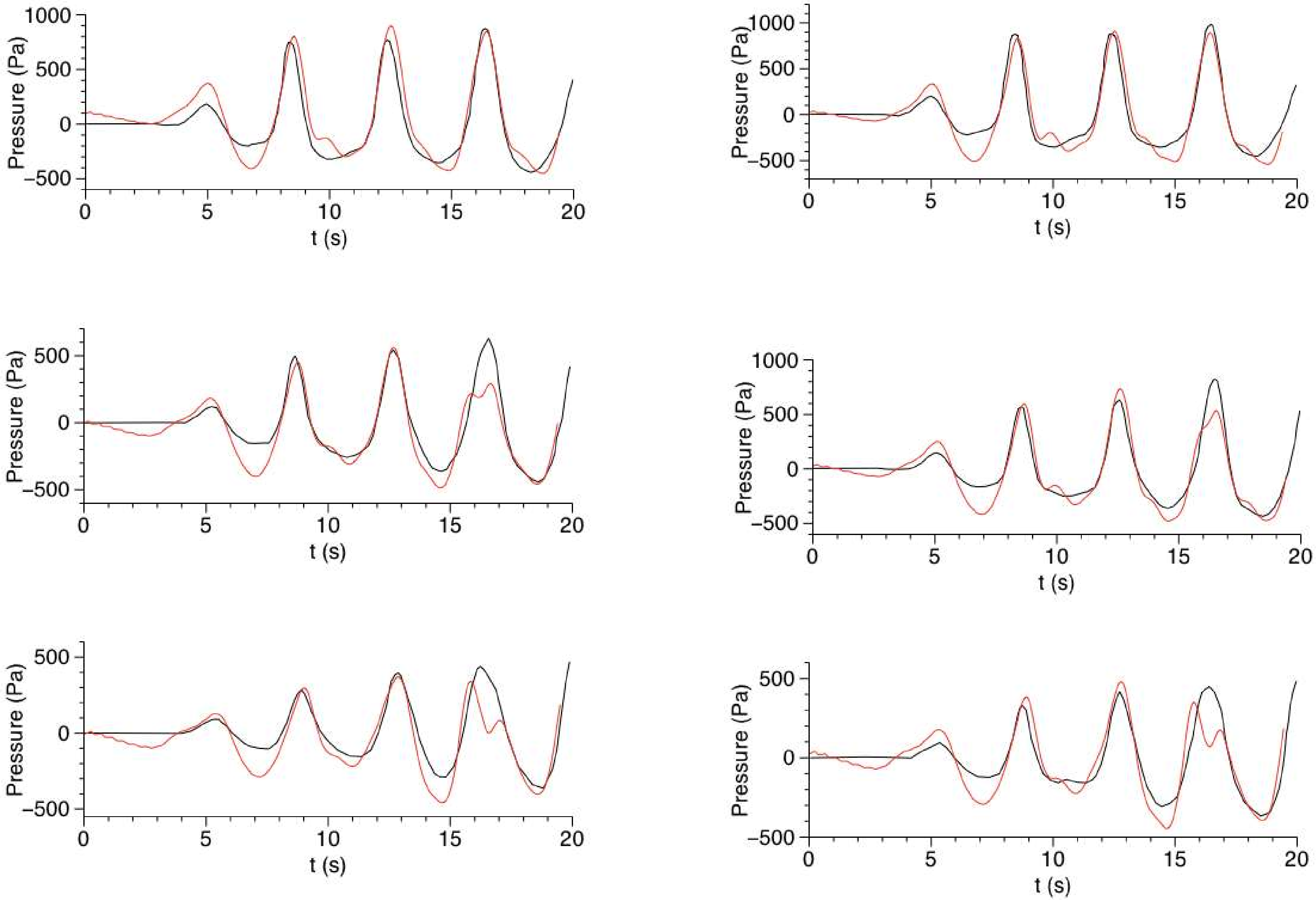
Comparison of pressure for solitary waves



Comparison of free surface for regular waves

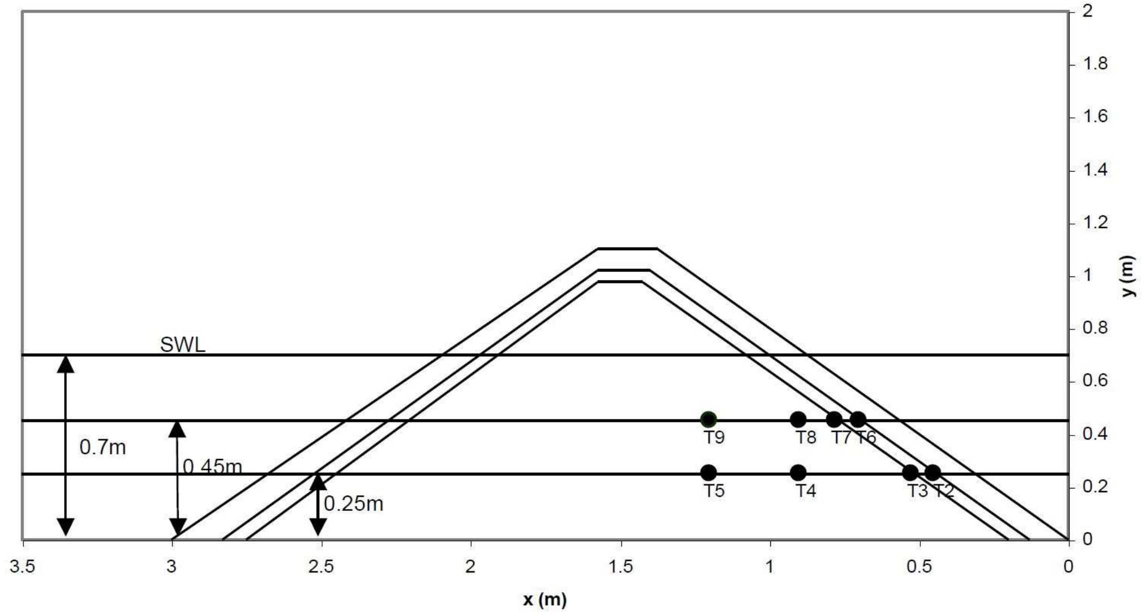


Comparison of pressure for regular waves



Rubble mound breakwater experimental setup

- SINTEF/NTNU laboratory, Trondheim
- Core : Diameter range = 1.4 to 2.8 mm, n : 0.414
- Filter layer : d_{50} = 0.02 m, Porosity, n = 0.33
- Armour layer : W_{50} = 1 kg, D_{n50} = 0.071 m, Porosity, n = 0.3



Arntsen, Ø. A., I. J. Malmedal, B. Brørs and A. Tørum (2003): Numerical and experimental modelling of pore pressure variation within a rubble mound breakwater. POAC'03 Trondheim, Norway, June 16-19, 2003.

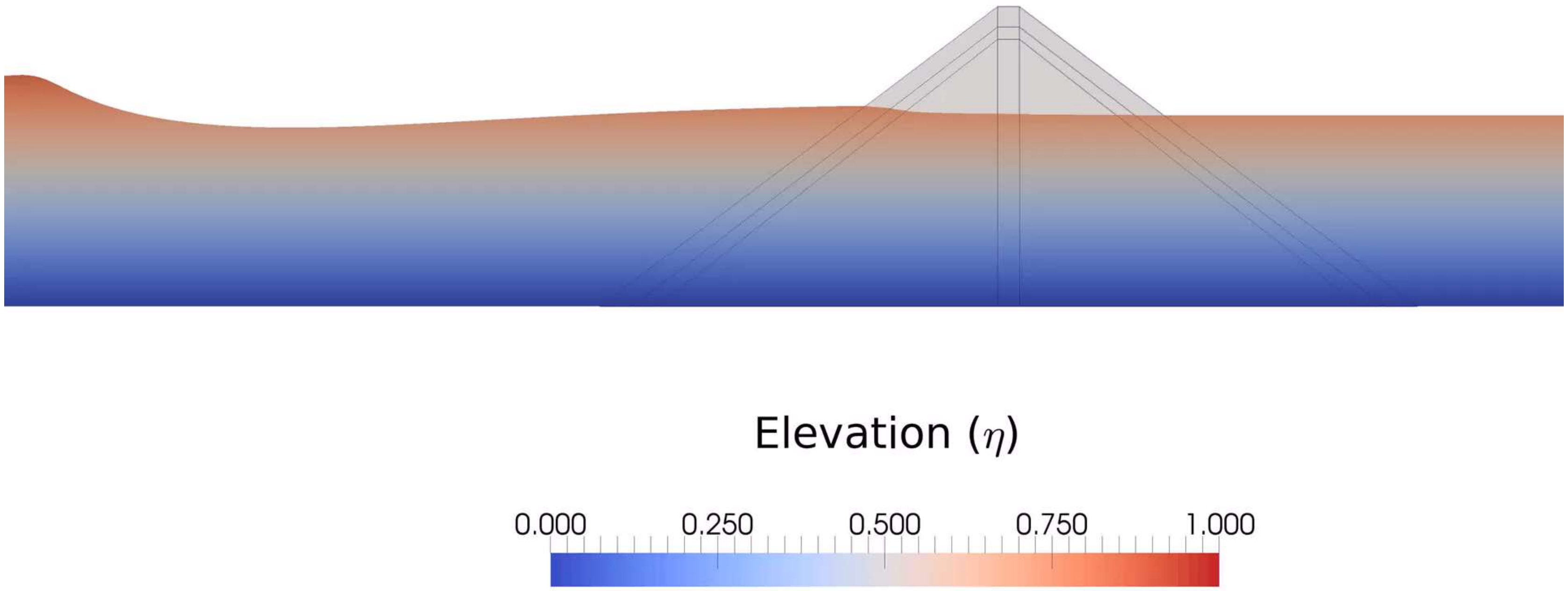

Side window view

Numerically simulated rubble mound breakwater

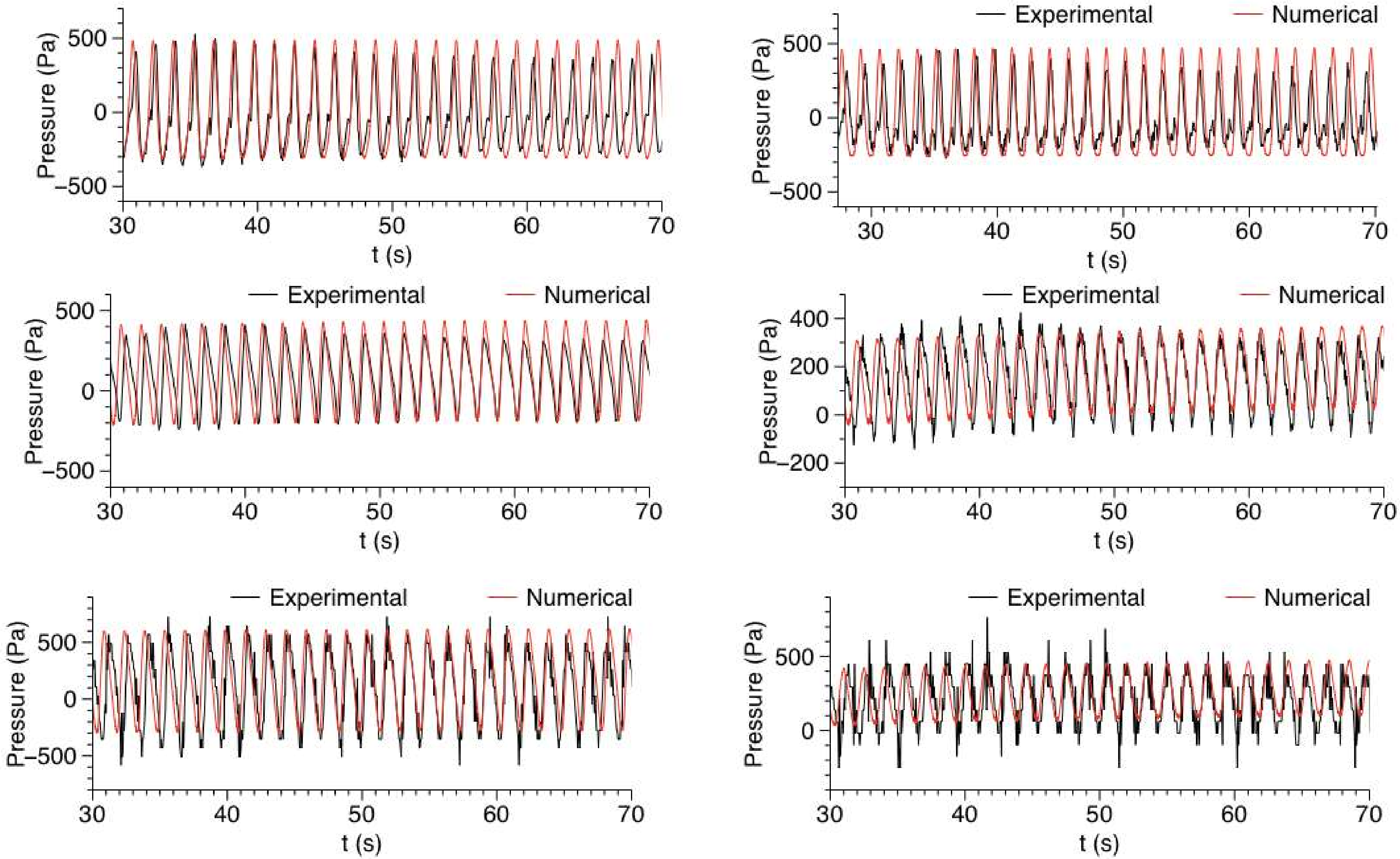
Grid size, Δx = 1 cm

NWT = 12.0 m × 0.01 m × 1.4 m

8 pressure probes inside the breakwater



Comparison of pressure for rubble mound breakwater



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Variables influencing stability of berm breakwaters

Wave Characteristics	Structural Characteristics	Material Characteristics	Other factors
Wave height	Lower front slope	Diameter (D_{50}) of the armour stone	Variation in SWL in front of the structure
Waveperiod	Initial berm width	Uniformity coefficient of the armour stones (D_{85}/D_{50})	Permeability of the structure
Wave groupiness	Berm elevation	Shape of the armour stones (percentage of round stones)	Flume width
Shape of the wave spectrum		Density of armour stones	
Number of waves attacking the structure		Roughnessof armour stones	
Angleof wave attack			

Extend the database for different structural characteristics

Measure pore pressure and velocities inside the berm breakwater

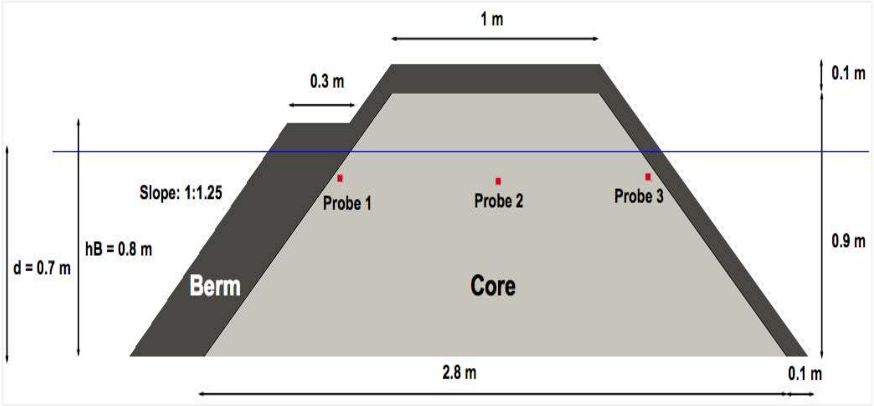
Optimal berm geometry based on lowest value of pore pressure and velocities compared to empirical relations

Extending the experimental database with detailed results, after validation for Berm breakwaters

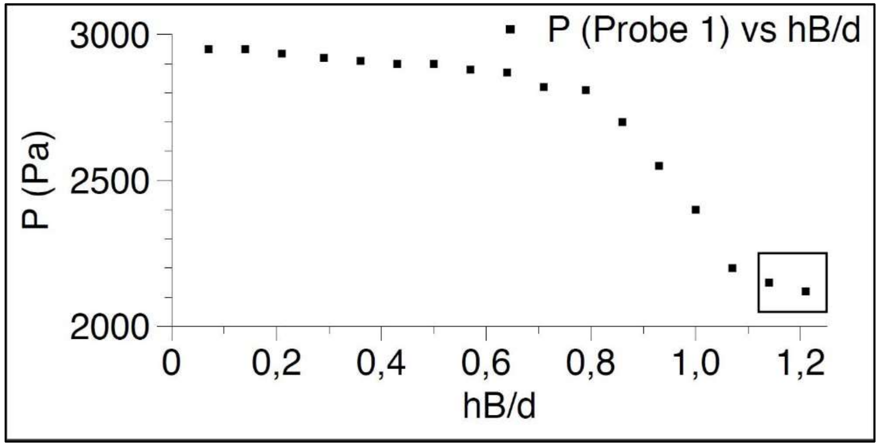
- ❖ Statically stable berm breakwater is modelled.
- ❖ Stability Number, N_s = 1.79
- ❖ Wave height-wave period number, H_0T_{0m}= 31.71
- ❖ Berm height to water depth ratio, h_b/d = 0.07 to 1.43
- ❖ Berm width, W = 0.05 to 1.5
- ❖ Berm slope, α = 1:1 to 1:1.35
- ❖ Berm: D_{n50} = 0.07 m, n = 0.51, α = 1000 and β = 1.0
- ❖ Core: D_{n50} = 0.03 m, n = 0.39, α = 600 and β = 2.2
- ❖ 5th-order Stokes waves
- ❖ Hs = 0.2 m, T = 1.5 s and d = 0.7 m.

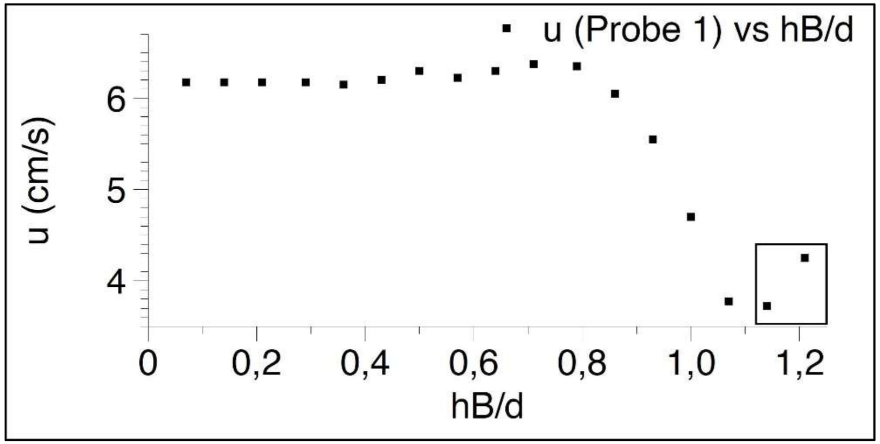
Type	Stability number, N_s	Dimensionless wave height-wave period number, H_0T_{0m}
Statically stable, no reshaping of berm, negligible erosion of front	<1.5 - 2	<20 - 40
Statically stable, some reshaping of berm in design sea states	1.5 - 2.7	40 - 70
Dynamically stable, larger reshaping, movement of stones	>2.7	>70

Classification of berm breakwaters according to PIANC MarCom Report of WG 40.



Berm height vs Velocity, pore pressure





- According to the rock manual, h_b = (0.5 - 0.9) Hs (m) above the design water level, i.e h_b = 0.8 to 0.88 m
- According to van der Meer, the berm level should be at least 0.6 H_S above the design water level.
- So according to theory, h_b/d ratio should be between 1.14 and 1.21
- Lowest values of pressure and velocities are seen around h_b/d = 1.0 - 1.2.

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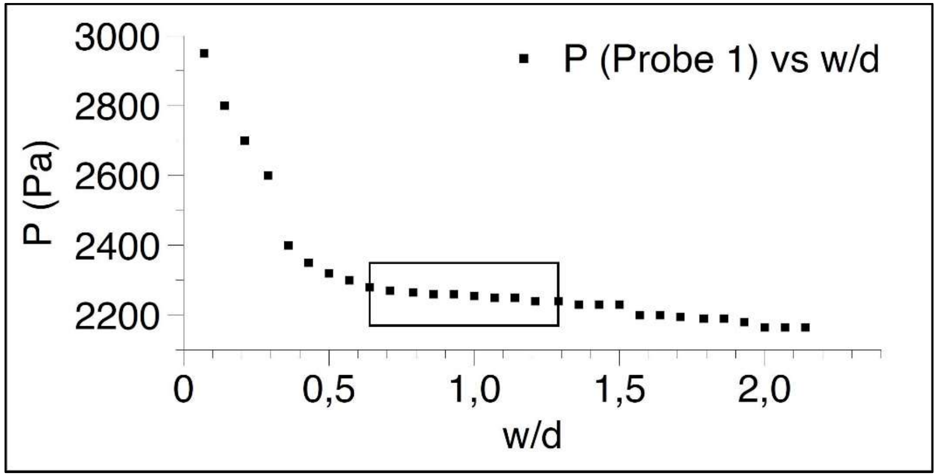
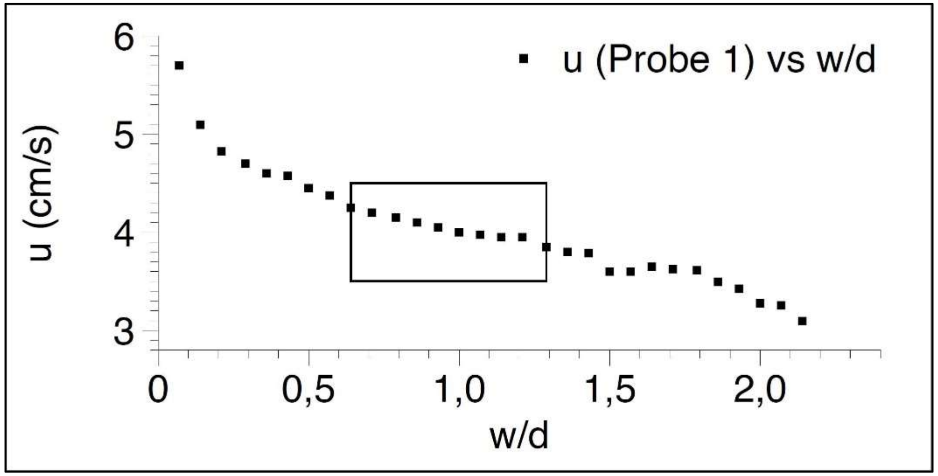
Berm width vs Velocity, pore pressure





- The berm width (W) : Cost and the expected recession
- The berm width based on the resiliency

$$B = R_{ec}/(P\%/100)$$
$$B_{min} = R_{ec} + 1D_{n50}$$

- For Rec=1.25 D_{n50} and P =10%, W = 0.88 m, W/d = 1.25
- For Rec=1.25 D_{n50} and P =20%, W = 0.44 m , W/d = 0.63

Type	Reshaping characteristics	P%	R_{ec}/D_{n50}
Very Resilient	Hardly reshaping	10 - 20 %	0.5 - 2
Good Resiliency	Partly reshaping	20 - 40 %	1.0 - 5.0
Minimum Resiliency	Fully reshaping	<= 70 %	3.0 - 10.0

Van Der Meer, J., and Sigurdarson, S., 2014. "Geometrical design of berm breakwaters". Coastal Engineering Proceedings, 1(34), p. 25.

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Summary

- Use of numerical modelling as a complementary tool to physical modelling.
- Numerical model validated for 2D Dam break, three-dimensional wave interaction with a porous abutment and a rubble mound breakwater
- Good agreement between experimental and numerical results.
- Combined use of physical models and numerical models can lead to different forms of improvements, mainly in increasing the quality at the same cost or obtaining the same quality at reduced cost.
- Further research using numerical models on berm breakwaters with different wave and material characteristics
- The effect of wave height, wave period, Dn50 and porosity on the wave kinematics insides the breakwater should be studied.