Numerical Investigation of Breaking Irregular Waves over a Submerged Bar With CFD

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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

Introduction

- Numerical modeling of breaking irregular waves

- Breaking irregular waves:
  - Breaking location, breaker type and height

- Wave propagation over a submerged bar:
  - wave shoaling, breaking, de-shoaling and decomposition processes

- Spatial evolution of irregular waves over a bar

Overview of numerical model: REEF3D

- Reynolds Averaged Navier-Stokes equation (RANS)
- Fifth-order WENO scheme for spatial discretization
- Third-order TVD scheme for time discretization
- Level set method for capturing the free surface
- k-ω turbulence model
- Fully MPI parallelized code

Irregular wave generation

- First order theory: linear superpositioning of regular wave components

$$\eta = \sum_{i=1}^{N} A_i cos\theta_i$$

$$A_i = \sqrt{2S(\omega_i)\Delta\omega_i}$$

$$\theta_i = k_i x - \omega_i t + \epsilon_i$$

$$k_i = \frac{2\pi}{\lambda_i}$$

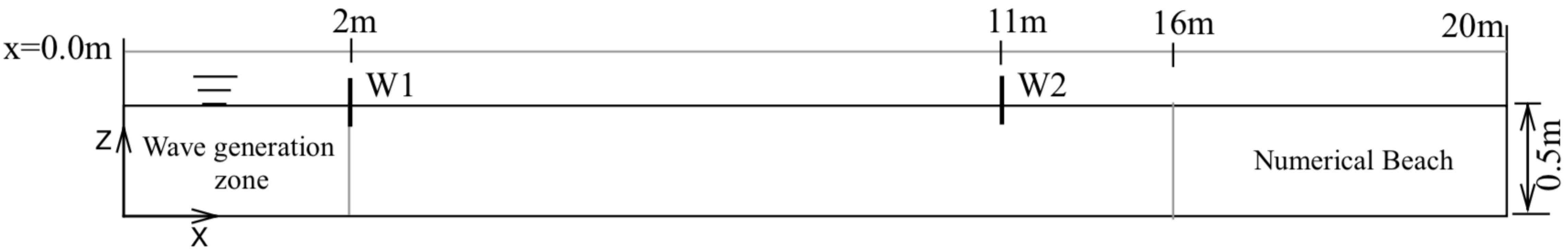
Second order theory by Dalzell (1999)

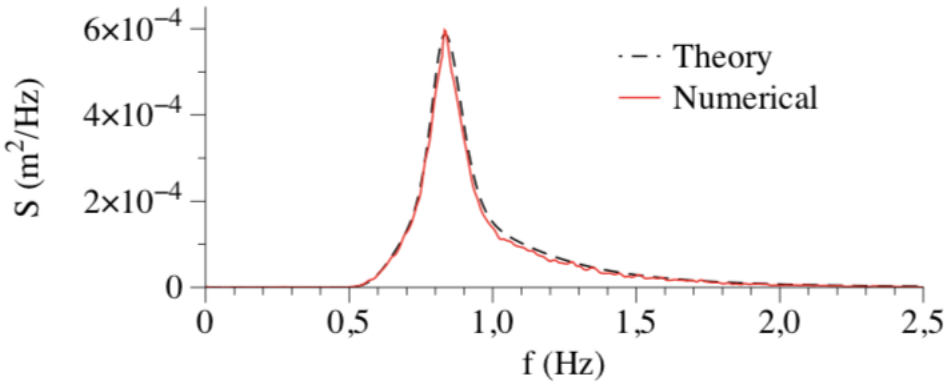
$$\eta = \eta_1 + \eta_2$$

$$u = u_1 + u_2$$

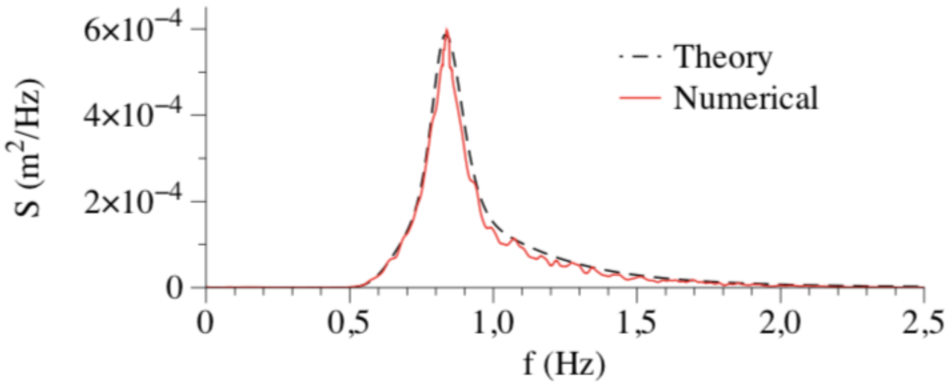
$$w = w_1 + w_2$$

Irregular wave propagation





(a) Wave Gauge at x = 2m

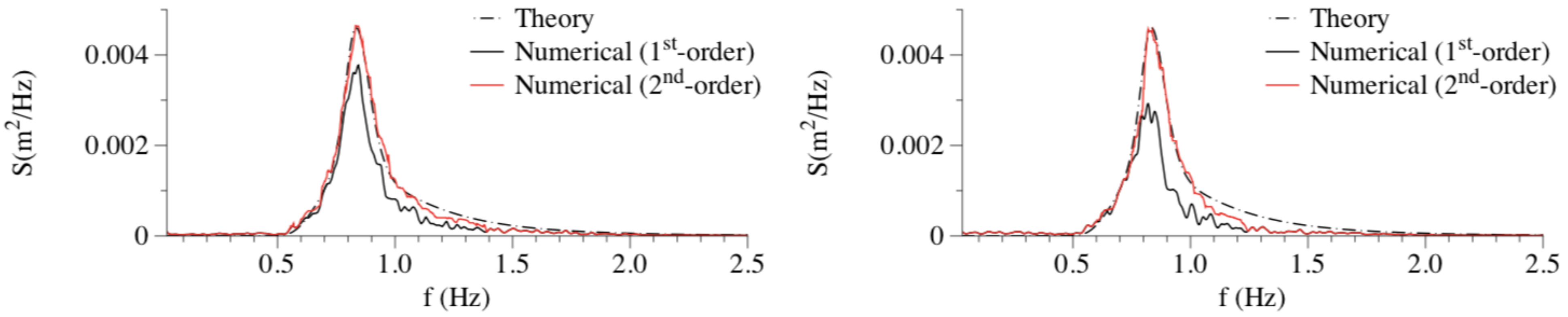


(b) Wave Gauge at x = 11m

H_s=0.04m and T_p=1.20s

Irregular wave propagation

H_s=0.14m and T_p=1.20s

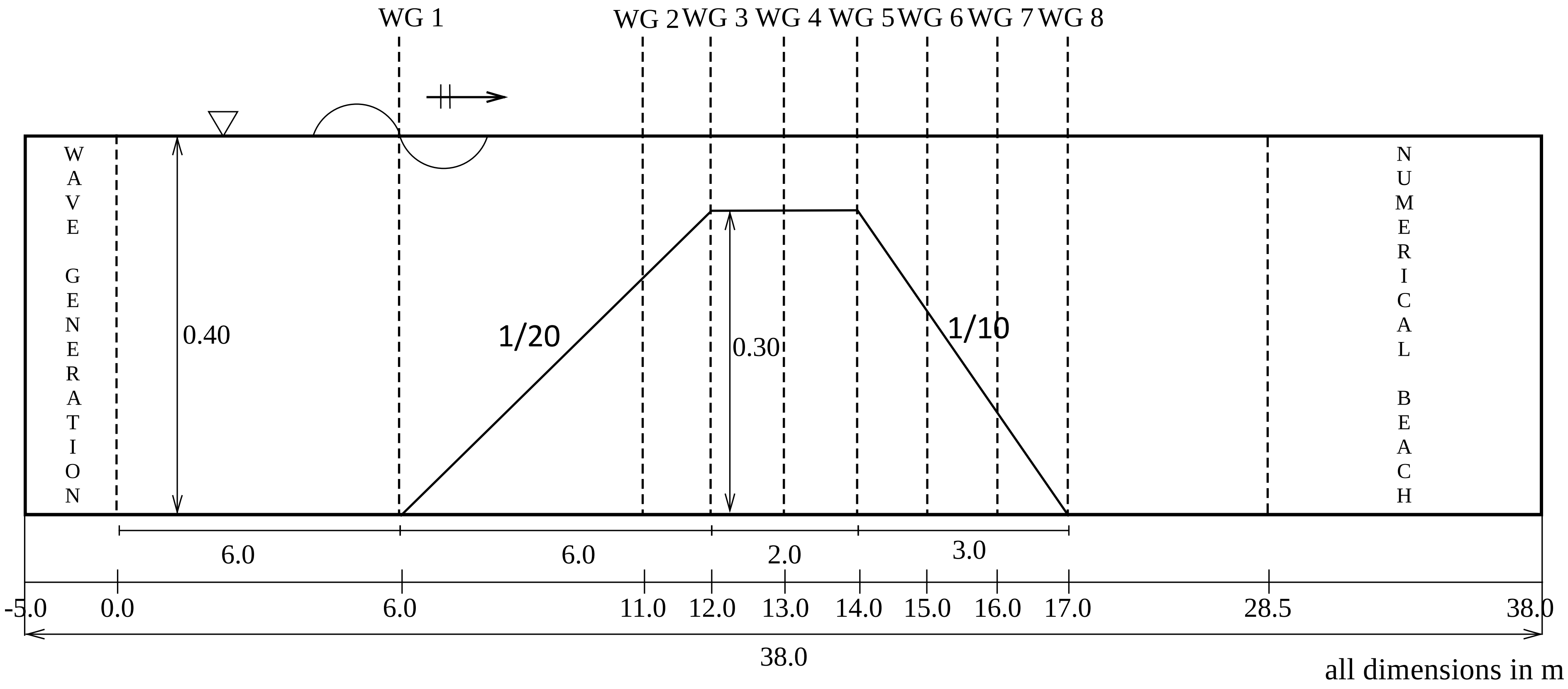


(a) Wave Gauge at x = 2m

(b) Wave Gauge at x = 11m

Wave-gauge location	Statistical parameters	Theory	Num.(1^{st}-order)	Num.(2^{nd}-order)	Error (1^{st}-order) (%)	Error (2^{nd}-order) (%)
At $x = 2m$	$H_s(m)$	0.140	0.1113	0.1363	16.92	1.2
	$T_p(s)$	1.20	1.22	1.21	1.7	0.83
At $x = 11m$	$H_s(m)$	0.140	0.1031	0.1306	24.21	6.0
	$T_p(s)$	1.20	1.22	1.21	1.7	0.83

Submerged bar: Numerical setup



- Numerical results are compared with the experiments by Beji and Battjes(1993)

Numerical setup

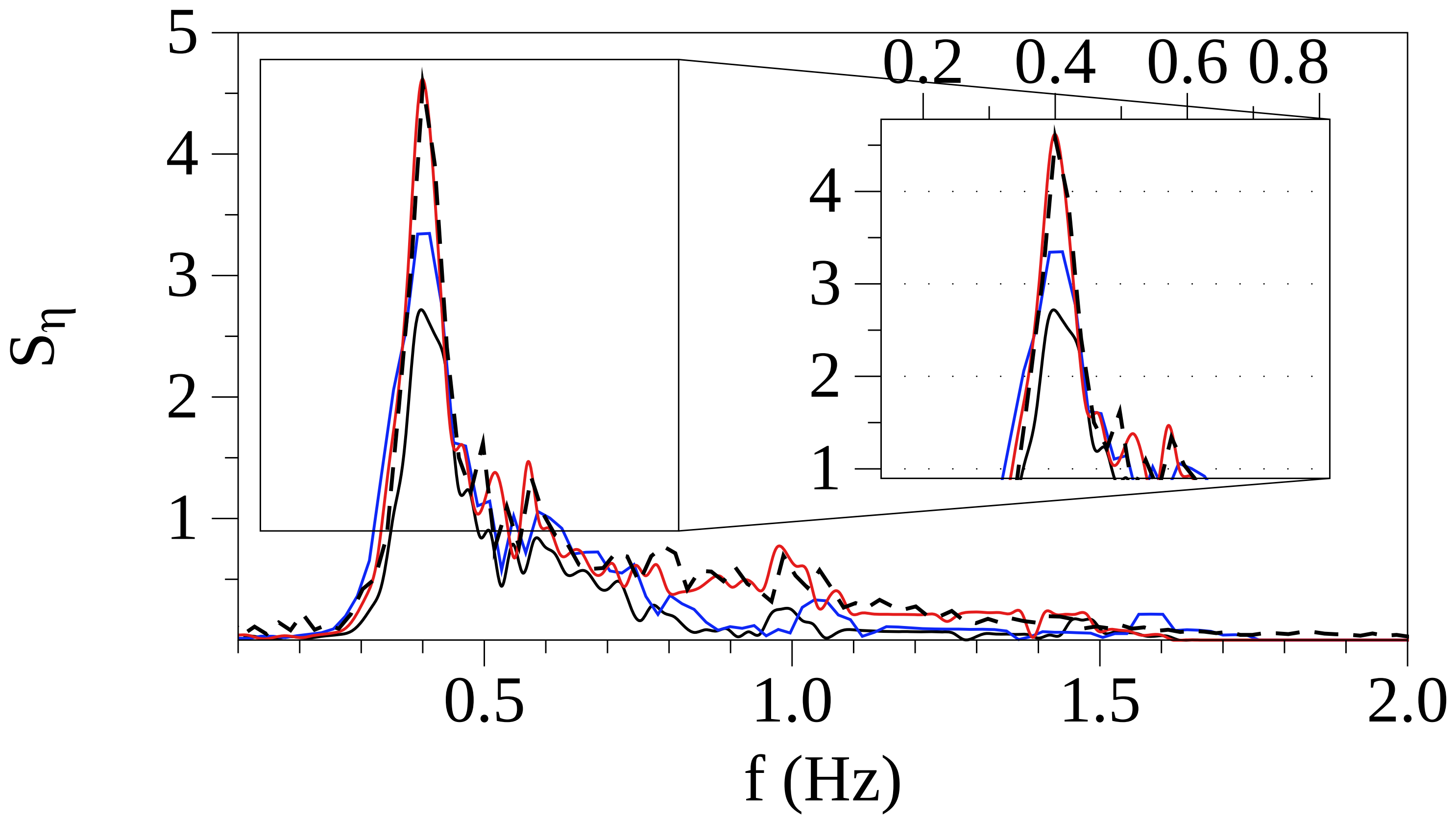
- JONSWAP spectrum:

$$S(\omega) = \frac{5}{16} H_s^2 \omega_p^4 \omega^{-5} exp\{\frac{-5}{4}(\frac{\omega}{\omega_p})^{-4}\}\gamma^{exp\{\frac{-(\omega-\omega_p)^2}{2\sigma^2 {\omega_p}^2}\}} A_\gamma$$

$$\gamma = 3.3 \; ; A_\gamma = 1 \text{ - } 0.287 \ln(\gamma); \sigma = 0.07, \text{ when } \omega < \omega_p; \sigma = 0.09, \text{ when } \omega > \omega_p$$

- Offshore significant wave height H_{so} = 0.054m, Peak period T_p = 2.5s
- Computational time: 120 hours on 512 processors with dx=0.01m
- Simulation time: 500s
- Wave spectral density is calculated with sampling interval of 0.02s.

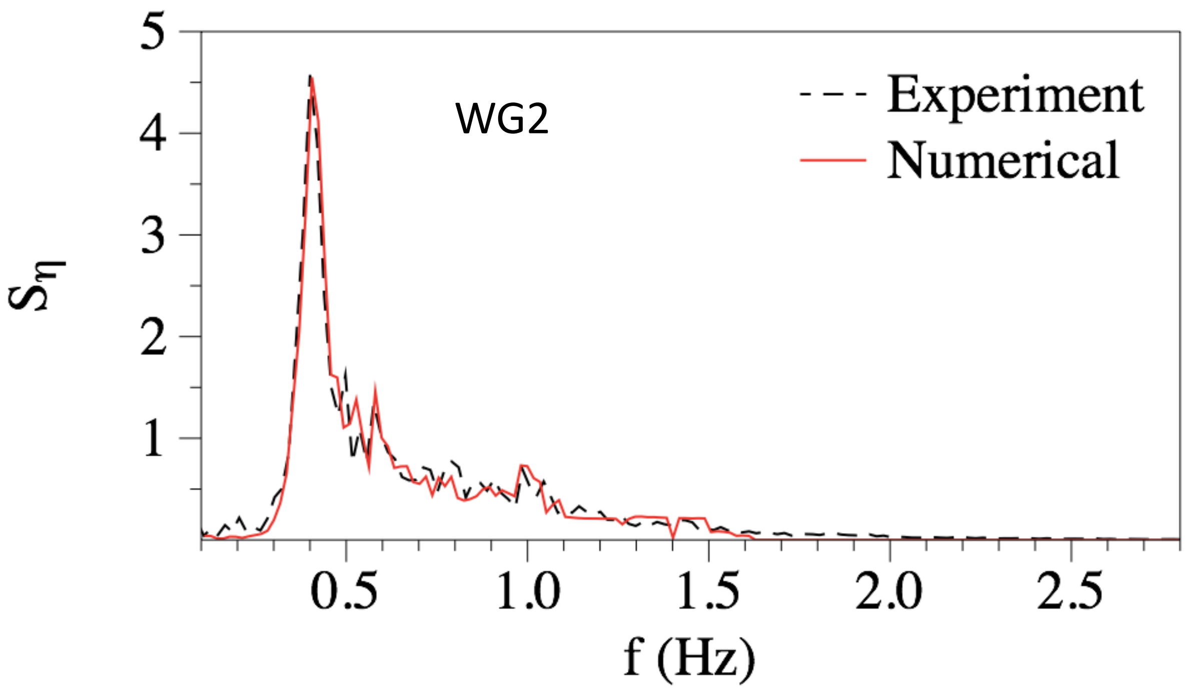
Convergence study

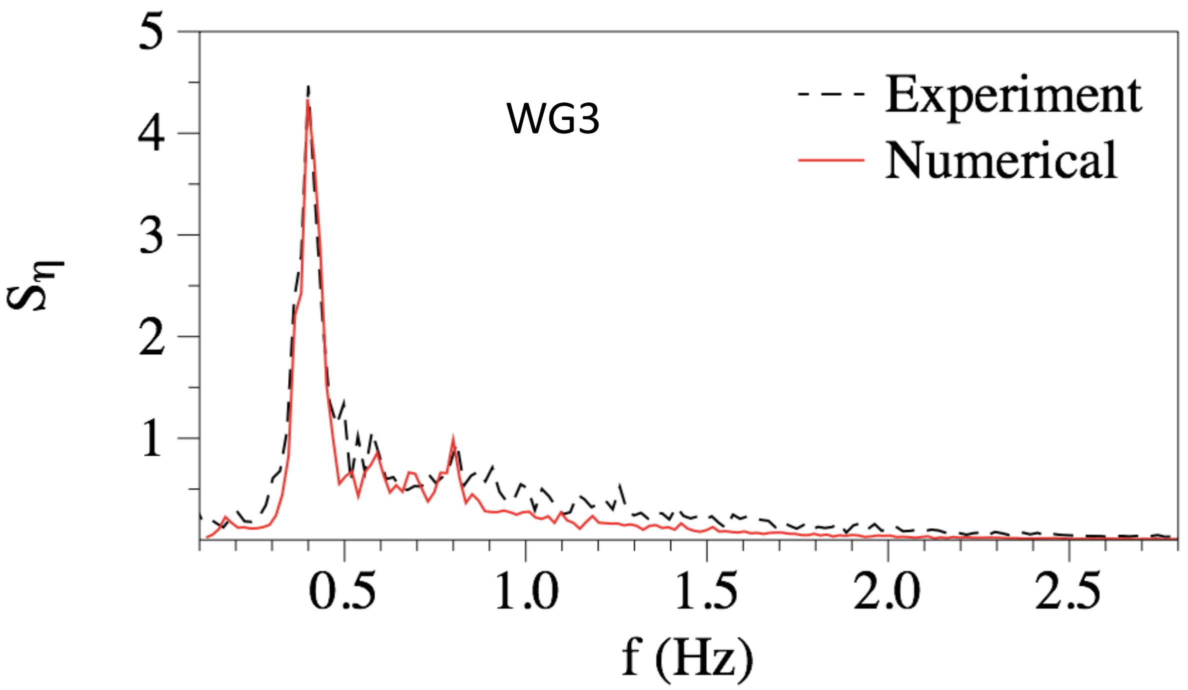


Wave gauge at x=11m

Red line for experiments
dashed black for dx=0.01m
blue line for dx=0.05m
solid black line for dx=0.10m

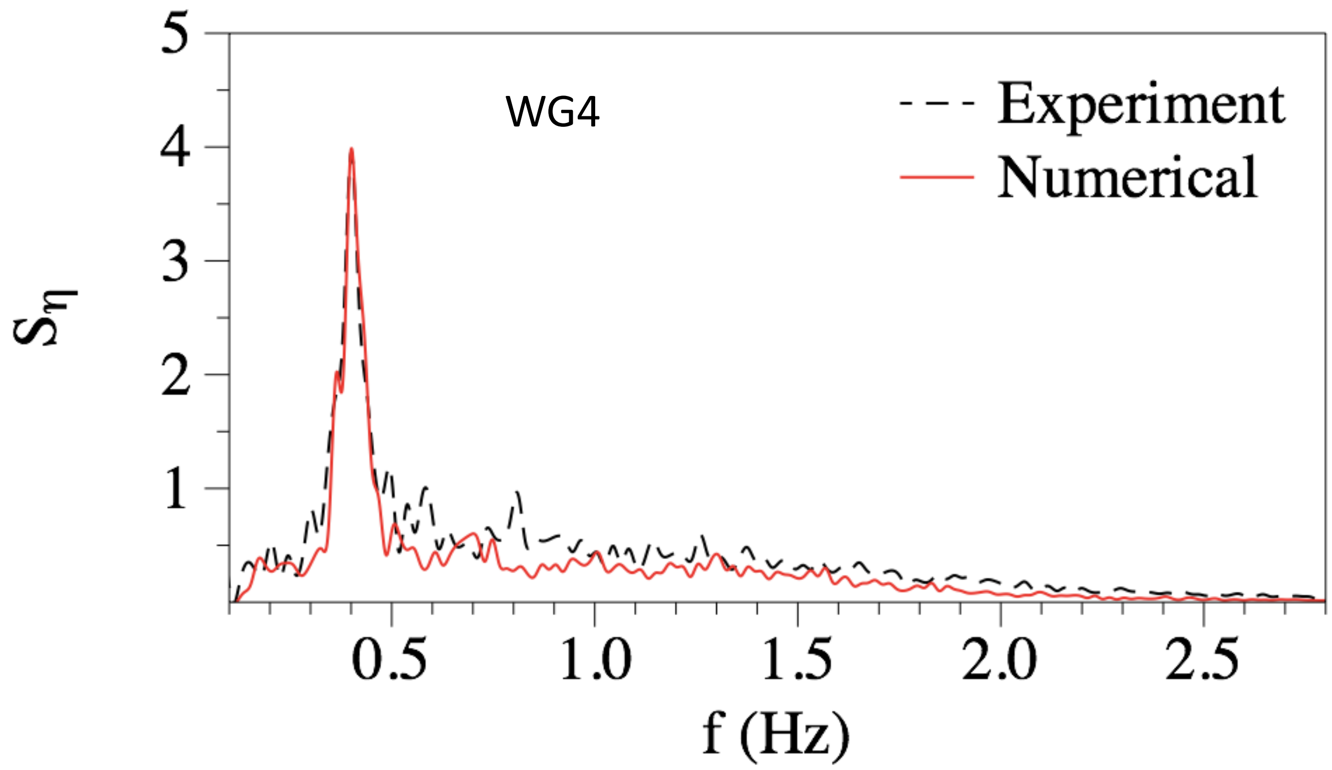
Weather side of slope: wave shoaling





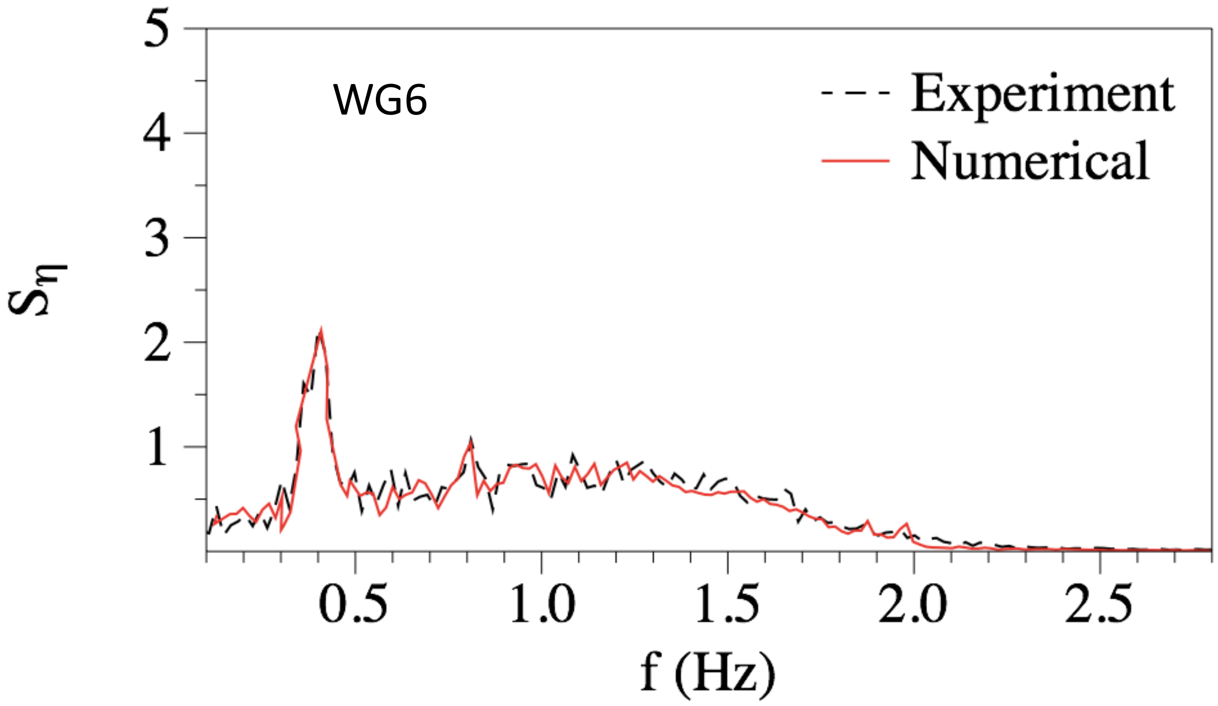
- A major portion of the spectral density between 0-1.5 Hz at WG2
- As the waves shoal, the contribution of spectral wave density towards higher frequencies increases

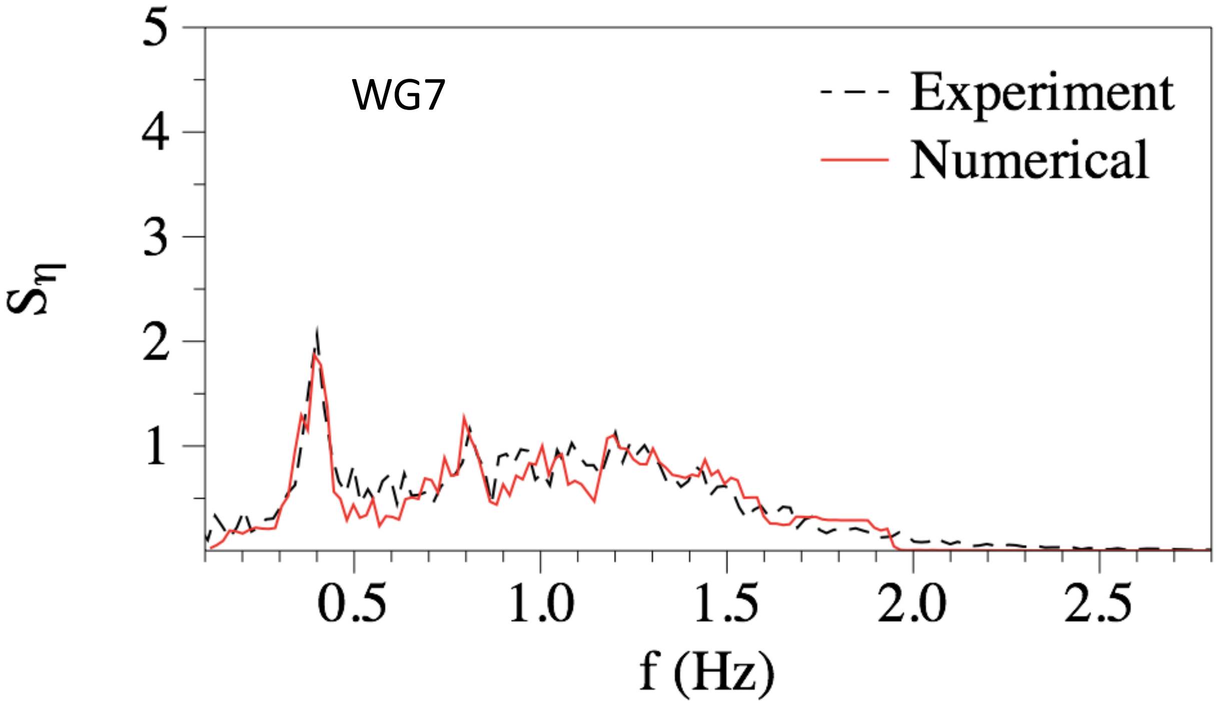
Flat part of the bar: wave breaking



- For the wave gauge at x=13m (WG4), some waves in the wave train have already broken
- The spectral peak is reduced
- The contribution of wave energy towards higher frequencies is further increased

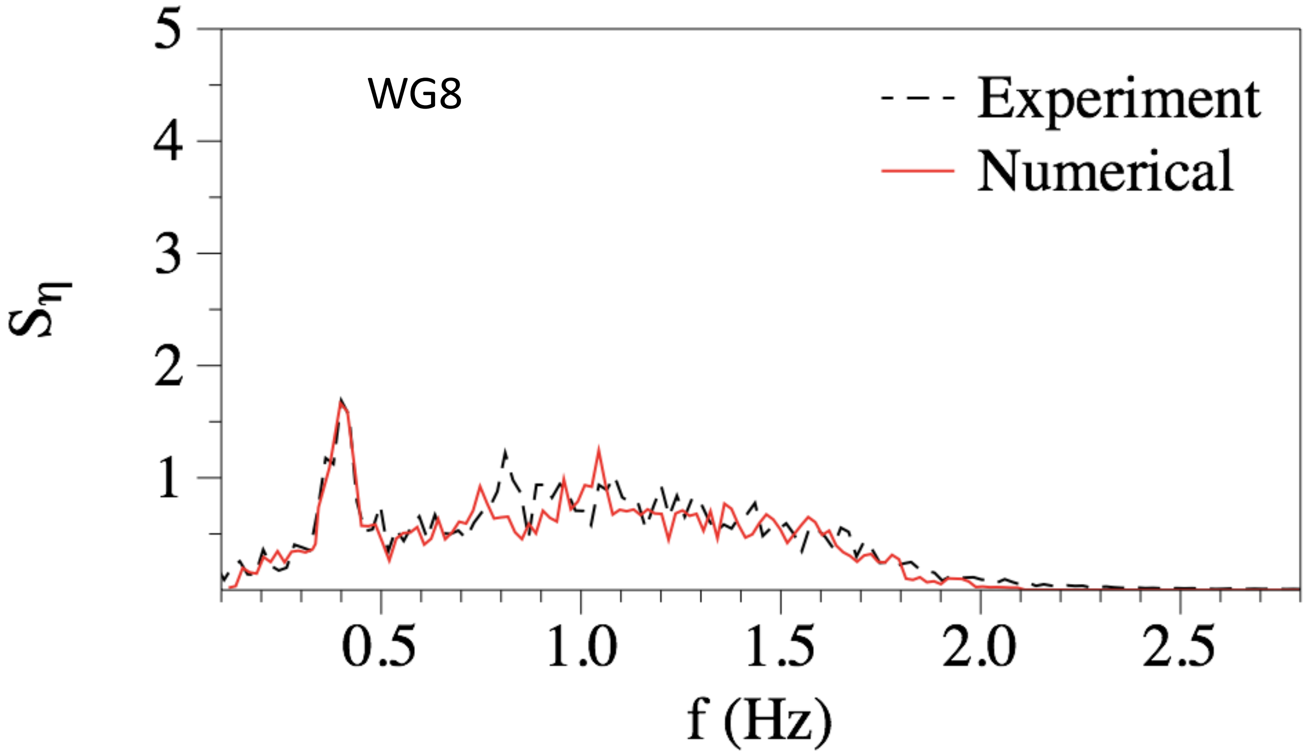
Lee side of slope: wave decomposition



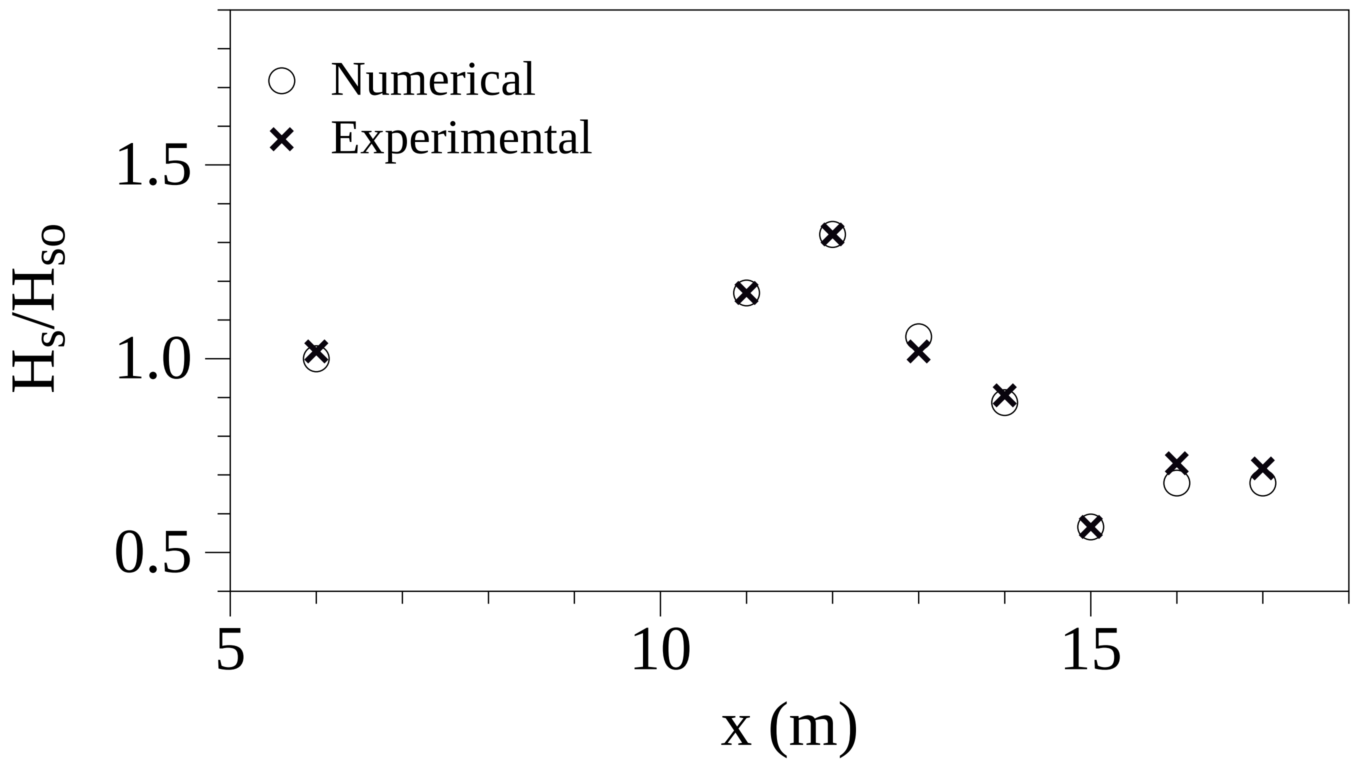


- Wave decomposition and wave deshoaling processes attributed to the increasing water depth on the lee side of the slope
- The contribution of the spectral wave density in the Higher-frequencies becomes significant

Lee side of slope: wave decomposition



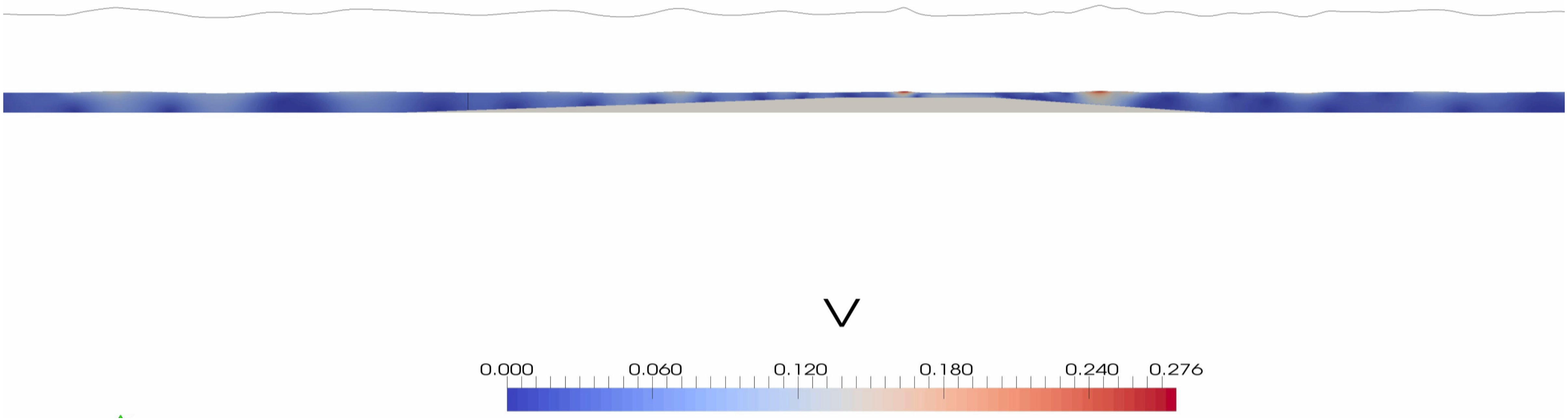
Comparison of local H_s and offshore H_{so}



- Wave breaking zone is between 12-14m (on the flat part of the bar), as seen from the reduction in the local H_s

- A slight increase in local H_s during wave de-shoaling process.

Breaking irregular waves over a submerged bar



Summary

- The numerically simulated results are consistent with the experiments by Beji and Battjes (1993)

- The spectral peak is reduced during wave breaking and some of the peak energy is dissipated during wave breaking and some is transferred towards higher frequencies

- Wave transformation processes along the bar are represented reasonably

- On going work:
  - Breaking irregular waves over a slope
  - Spectral characteristics such as skewness and band width parameter
  - Characteristics and geometric properties

Acknowledgements

The Research Council of Norway

Project Number: 246810

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Project Number: NN2620

Thank you for your attention