Coupled CFD and depth-averaged wave-current model for coastal and offshore applications

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22 Sep 2025

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PRESENTATIONS and INFORMATION

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1. Introduction
2. Numerical Methodology
3. Validation and Application
4. Conclusion

Introduction

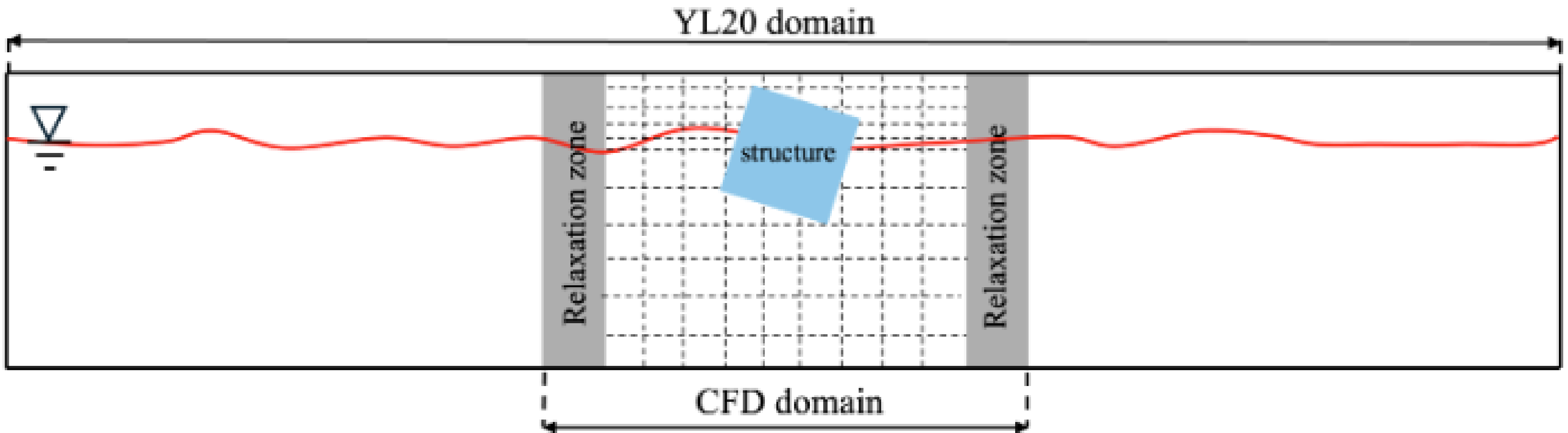
CFD Challenges: Time Consuming

Time consuming to Model wave-structure interactions over long simulation durations using conventional CFD tools due to Large computational zones.

- Large domain at upstream: fine mesh to assure wave propagation
- Large domain at downstream: to minimize wave reflection.
- Large domain at two sides: Avoid wave reflection from the side boundaries

Methodologies: depth-integrated YL20 wave–current model (YL20) + CFD coupling (Star-CCM+)

Using the coupling strategy where the **YL20 model** is used to compute the far-field wave solution and the CFD solver is used to solve the near-field fluid domain, where the structure to be studied is located



Coupling Strategy Between YL20 model and StarCCM+

Numerical Methodology

Domain Configuration

$S_{\emptyset} = -\gamma\rho(\emptyset - \emptyset^*)$: User defined source term (Potential solver results)

- The simulation domain: three zones
  - far-field zone: potential zone
  - Near field zone: CFD zone
  - Overlay zone: forcing zone (potential solver -> CFD)
- Forcing zone (potential solver -> CFD):
  - Governing Equation:

$$\frac{\partial}{\partial t}\int_V \boldsymbol{\rho v} dV + \oint_A \boldsymbol{\rho v \otimes v da} = -\oint_A \boldsymbol{\rho I \cdot da} + \oint_A \mathbf{T} \cdot \boldsymbol{da} + \int_V \boldsymbol{f_b dV} + \int_V \boldsymbol{S_\phi dV}$$

$S_{\emptyset} = -\gamma\rho(\emptyset - \emptyset^*)$: User defined source term (Potential solver results)

  - The source term:

$q_{\mathbf{u}} = -\gamma\rho(\mathbf{u} - \mathbf{u}^*)$ $\quad \mathbf{u}\ \alpha_w$ are the solutions in CFD regions.

$q_{\alpha w} = -\gamma(\alpha_w - \alpha_w^*)$ $\quad \mathbf{u}^*\ \alpha_w^*$ are the solutions from the HOS.

  - Blending function

$\gamma = \gamma_0 cos^2(\pi\, x^*/2)$ $\quad \gamma_0$ is the forcing constant

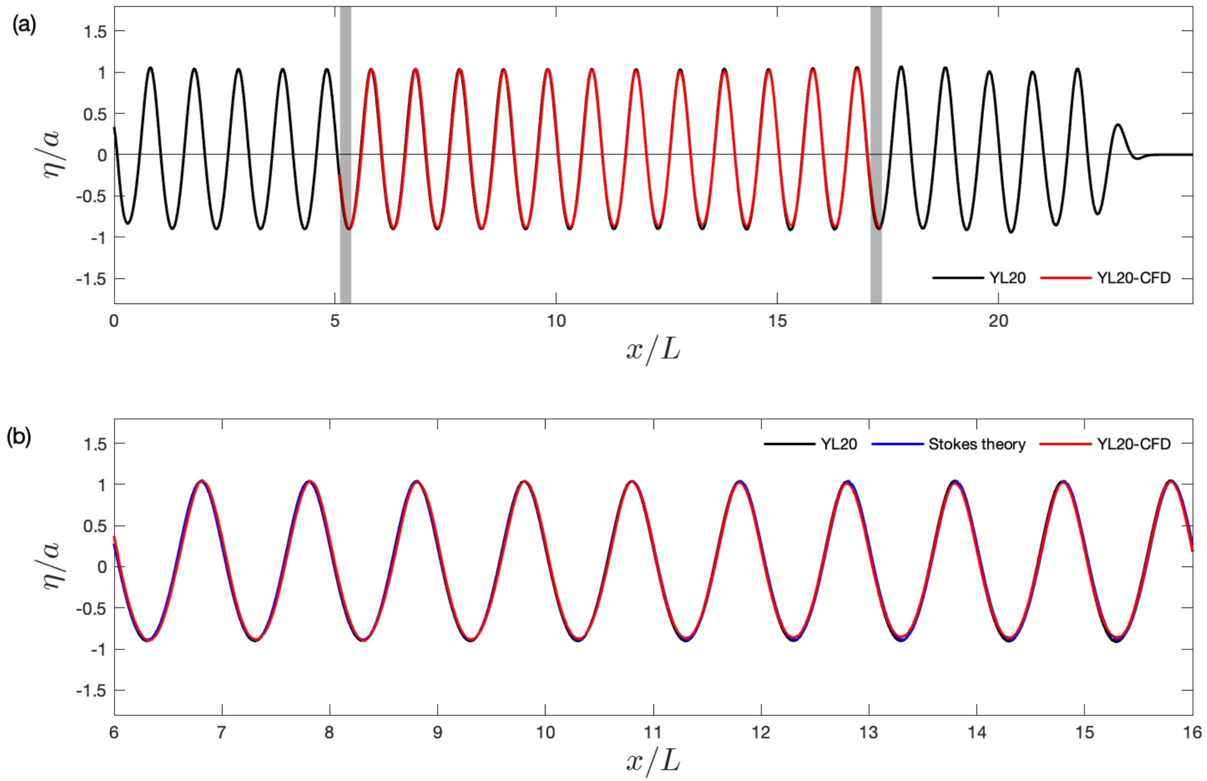
x^* is distance to the forcing zone BC

  - Derivative of the source terms: $\partial q_{\mathbf{u}}/\partial \mathbf{x} = -\gamma\rho \qquad \partial q_{\alpha w}/\partial \mathbf{x} = -\gamma$

Numerical Validation

1. Nonlinear regular wave propagation in deep water

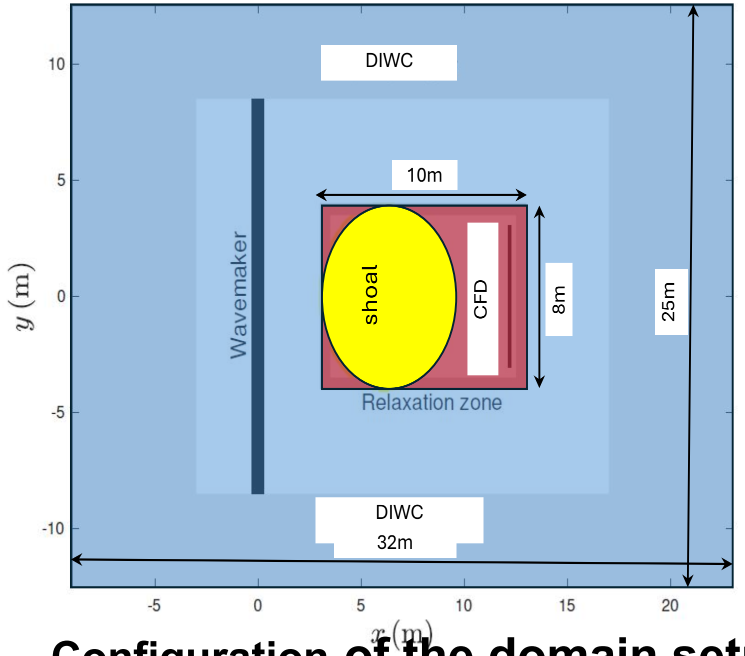
- A monochromatic wave train:
  - Amplitude a = 0.02m
  - Period T = 0.7 s
  - Constant depth h = 1 m.
  - The CFD subdomain extends from x = 5.1L to x = 17.4L within the YL20 flume, resulting in an effective length of 12.3L.



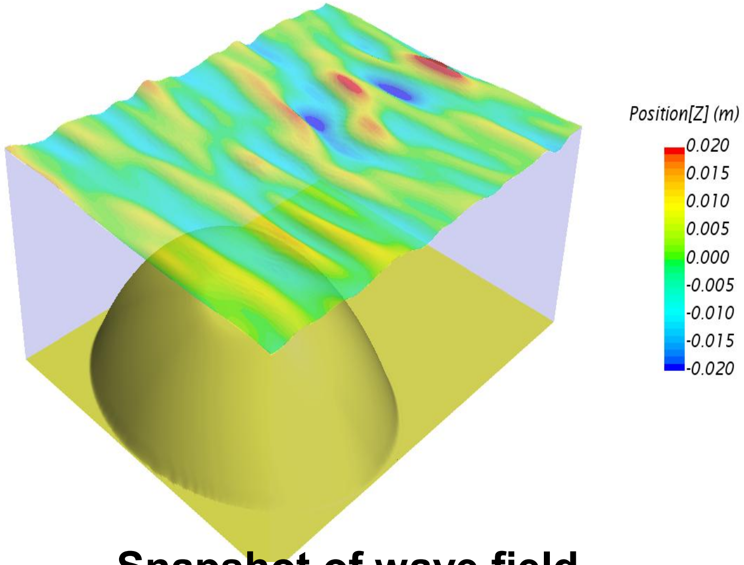
Comparison in the CFD domain (6 ≤ x/L ≤ 16) among the YL20 model, the YL20-CFD model, and third-order Stokes theory

2. Multi-directional random wave propagation over a submerged shoal

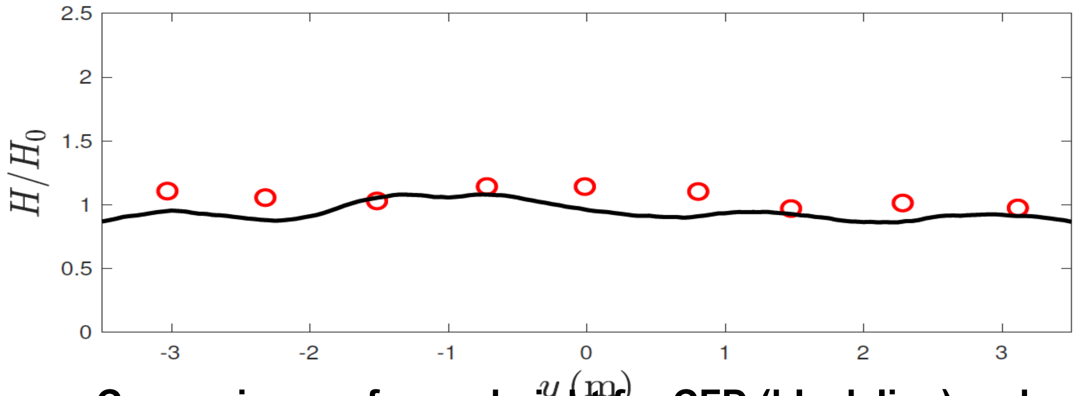
- The shoal had a major radius of 3.96 m and a minor radius of 3.05 m, with a still-water depth of 0.4572 m and a crest depth of 0.1524 m.
- a peak wave period of 1.3 s and a target significant wave height of 2.54 cm, with a low spectral peakedness parameter $\gamma = 2$.



Configuration of the domain setup



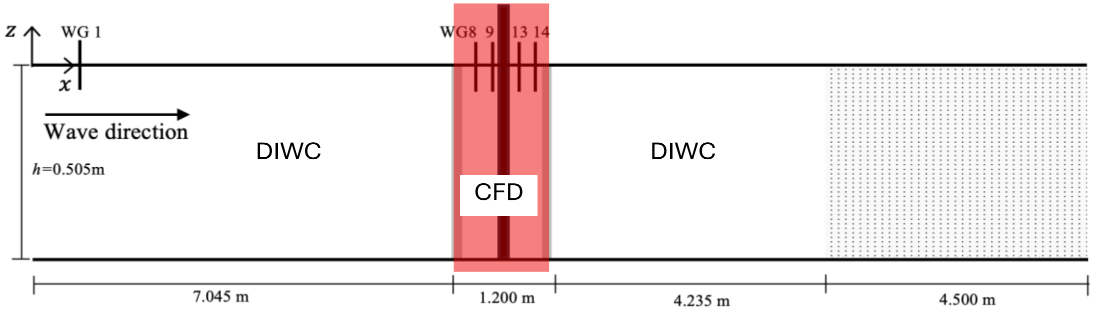
Snapshot of wave field

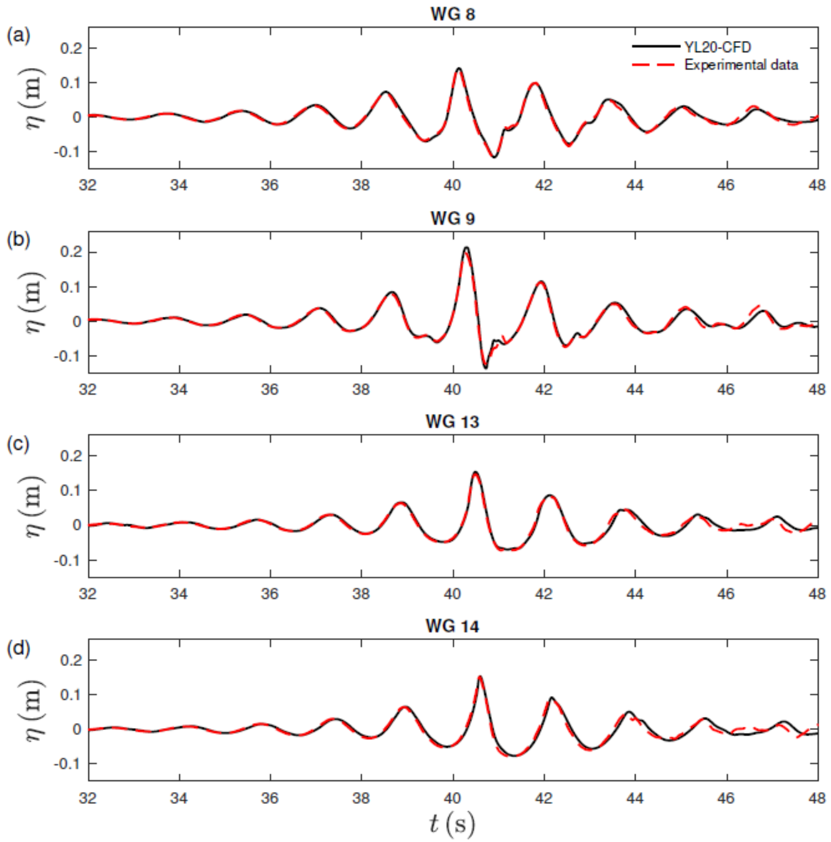


Comparisons of wave height for CFD (black line) and experiment (red dot) at x=21.2m.

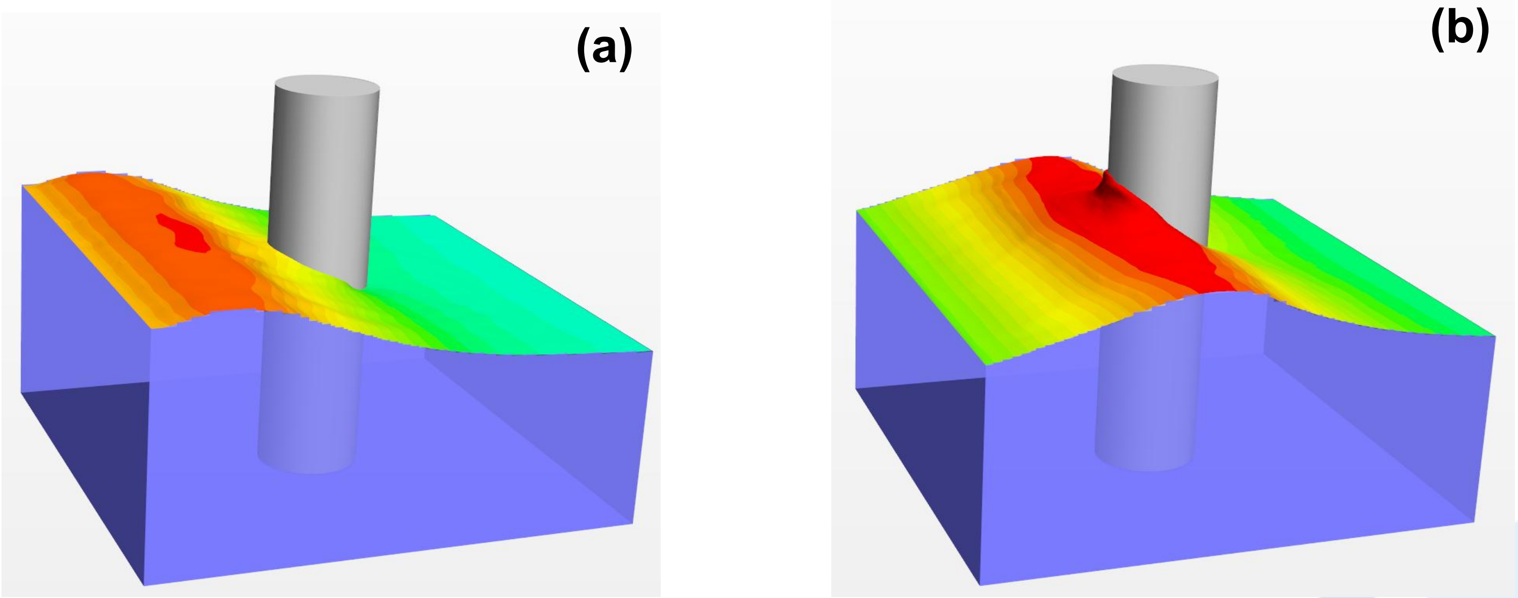
3.Focusing wave interacts with a circular cylinder

A focusing wave group with JONSWAP-type amplitude distribution with a peak frequency of f = 0.61 Hz, and amplitude A=0.14m is generated in the wave flume with water depth h=0.505m.





Comparisons of surface elevation at wave gauges



Snapshot of wave at maximum cylinder force (a) and maximum surface heiht (b)

Conclusions

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❖The YL20–CFD model was developed to enhance the efficiency of a Navier-Stokes solver by coupling it with the depth-integrated YL20 model

❖The YL20–CFD model provides an efficient mechanism for wave– current generation and absorption through relaxation zones.

❖ The YL20–CFD model significantly reduces the computational domain by confining the Navier–Stokes solver to the vicinity of the target structure, where high resolution is most critical.

❖The YL20–CFD approach significantly reduces simulation time by initializing the CFD domain with flow fields computed from the YL20 model.

Acknowledgments

The authors are grateful to the National Research Foundation of Singapore, PUB (Singapore's National Water Agency) and National University of Singapore for supporting this work done in the Coastal Protection and Flood Resilience Institute (CFI) Singapore under the Coastal Protection and Flood Management Research Programme (CFRP). The author The conclusions put forward in this presentation reflect the views of the authors alone and not necessarily CFI Singapore or any of the supporting entities.