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A numerical investigation of waves interacting with rigid and flexible structures

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1. Introduction

Waves impacting on structures, e.g. dams or wave energy devices, are complex **fluid-structure** interaction phenomena (Fig. 1). This may lead to flow **modifications** and **structural damages**. The structure impacted by the fluid can behave rigid or flexible. In the latter (Fig. 2), the structure **deforms** under wave loading, making the wave-structure interaction (**WSI**) effects even more relevant. An accurate understanding of WSI is challenging.

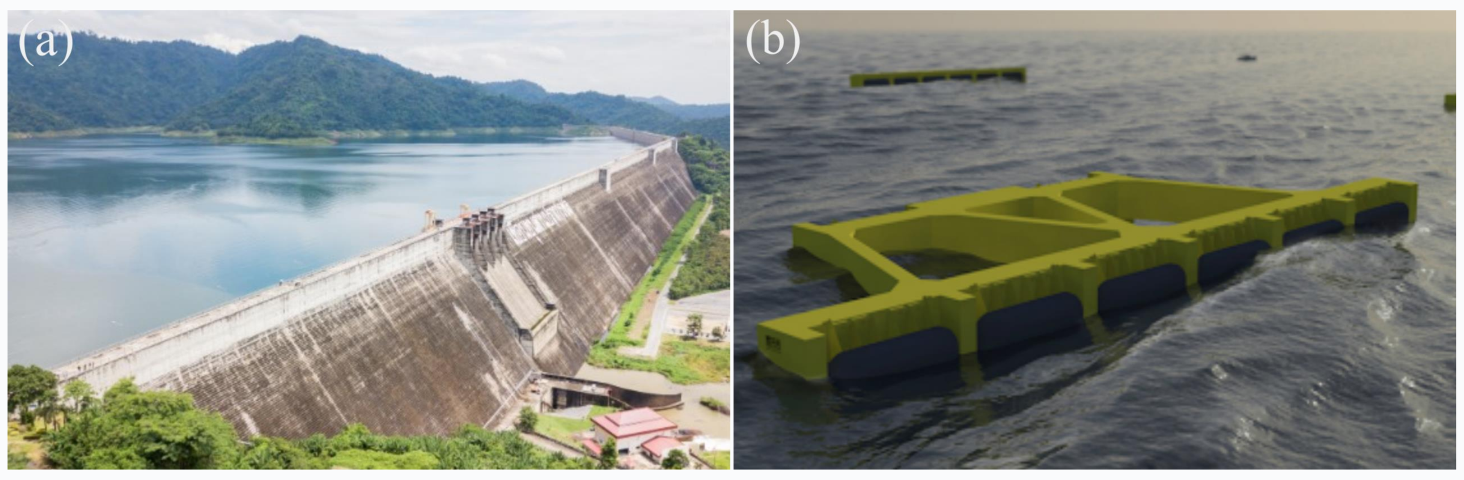

Fig. 1. (a) A hydropower dam and (b) a wave energy device.

1.1 Aim and objectives

This study aims to investigate **WSI** through the following objectives:

- **Validate** an existing numerical toolbox;
- Conduct numerical experiments of **waves** impacting on **rigid/flexible** structures;
- Formulate and validate the **governing** dimensionless **parameters** for WSI.


Fig. 2. Numerical simulation of a solitary wave impacting a flexible plate.

2. Methodology

The open source toolbox **solids4foam**[2] implemented in **Foam-Extend** 4.0 is used. This toolbox solves fluid-solid interaction problems based on the **Finite Volume Method.** The fluid and solid governing equations are individually solved and **coupled** through a **partitioned approach,** consisting in an exchange of information at the fluid-solid interface (Fig. 3).

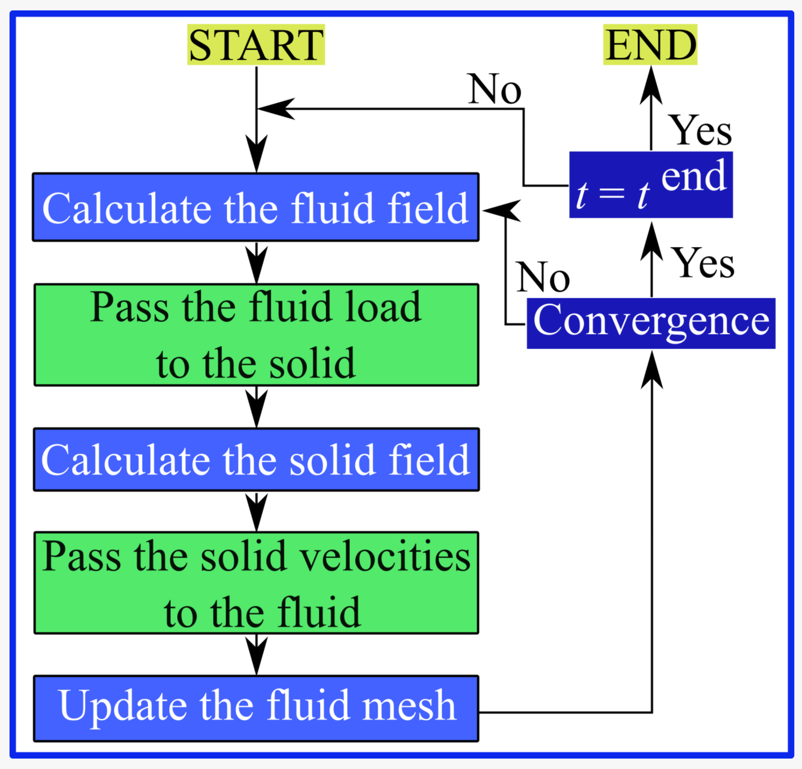

Fig. 3. Coupling method in solids4foam[2].

2.1 Validation of solids4foam

The numerical model was **validated** with:

- **Laboratory tests**[6] and an **analytical solution**[7] for linear waves impacting a vertical and rigid wall;
- **Numerical results**[3] for solitary wave forces at a vertical dam;
- **Experiments**[5] for solitary wave overtopping at a vertical dam (Fig. 4).

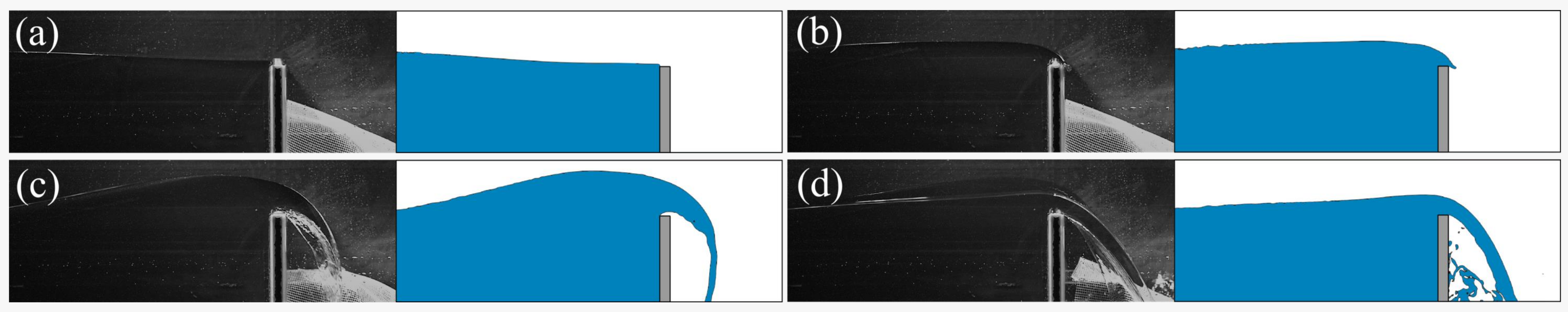

Fig. 4. Validation of solids4foam with experiments[5] for wave overtopping[1].

3. Results and Discussion

4.1 Tsunamis impacting on dams

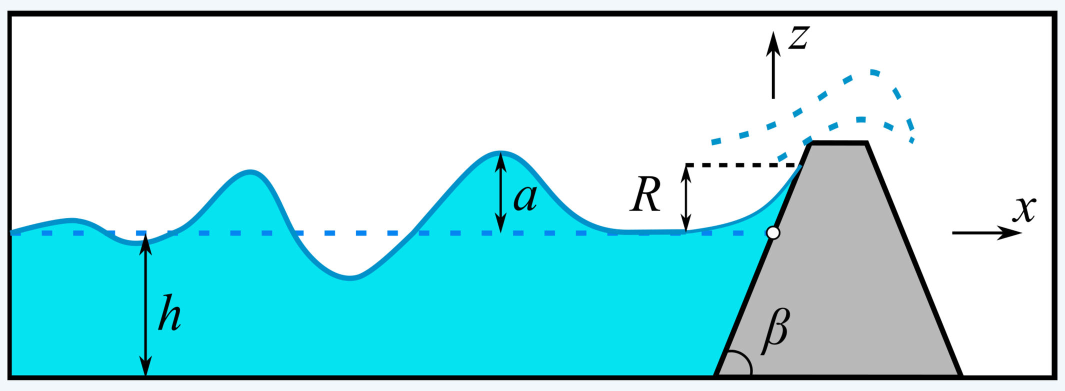

Fig. 5. Numerical set-up.

Tsunamis impacting on **dams** were investigated with a 2D numerical set-up (Fig. 5). A range of **wave types** and dam **inclinations** β = 60 to 90° were simulated.

The **wave run-ups** R relative to the water depth h were approximated in function of β and the wave amplitude relative to the water depth a/h (Fig. 6a). The **horizontal forces** F_H on the dam are normalised with the hydrostatic force F_h and compared with **predictions**[4] for the tests without **overtopping** (Fig. 6b). These equations[4] predict the numerical F_H well with deviations of ±10%, operating on the **safe side** for most tests.

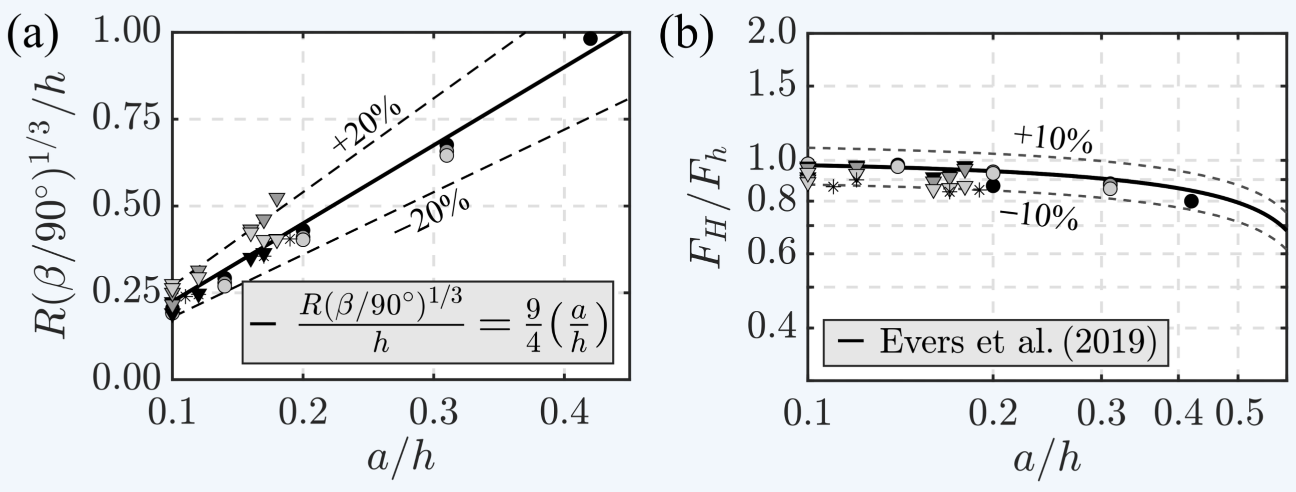

Fig. 6. Numerical data: (a) $R(\beta/90°)^{1/3}/h$ versus a/h described with an empirical equation and (b) comparison of F_H/F_h with predictions[4] versus a/h.

4.2 Waves impacting on flexible plates

Fig. 7a shows the **water pressure** $p(z)$ on **rigid** and **flexible** plates impacted by a linear wave. The Young's modulus of the plates is $E = 2{\cdot}10^5$ and 1 MPa for the rigid and flexible plate, respectively. The impacting wave deformed the **flexible plate**, resulting in a **smaller** $p(z)$ on the flexible than the rigid plate.

4.3 Governing parameters for WSI

The following 5 **quantities** were derived as the parameters governing **WSI**:

$$\Pi_1 = H/h,\ \Pi_2 = T(g/h)^{1/2},\ \Pi_3 = \rho_s s/\rho h,\ \Pi_4 = D/\rho g h^5,\ \Pi_5 = l/h$$

H is the wave height, T the wave period, ρ the water density, ρ_s the plate density, D the plate rigidity, s the plate thickness, l the plate length and g the gravitational acceleration. Relative horizontal plate displacements d_x/h are compared for tests under different conditions and **conservation** of $\Pi_{1,..,5}$ (Figs. 2, 7b).

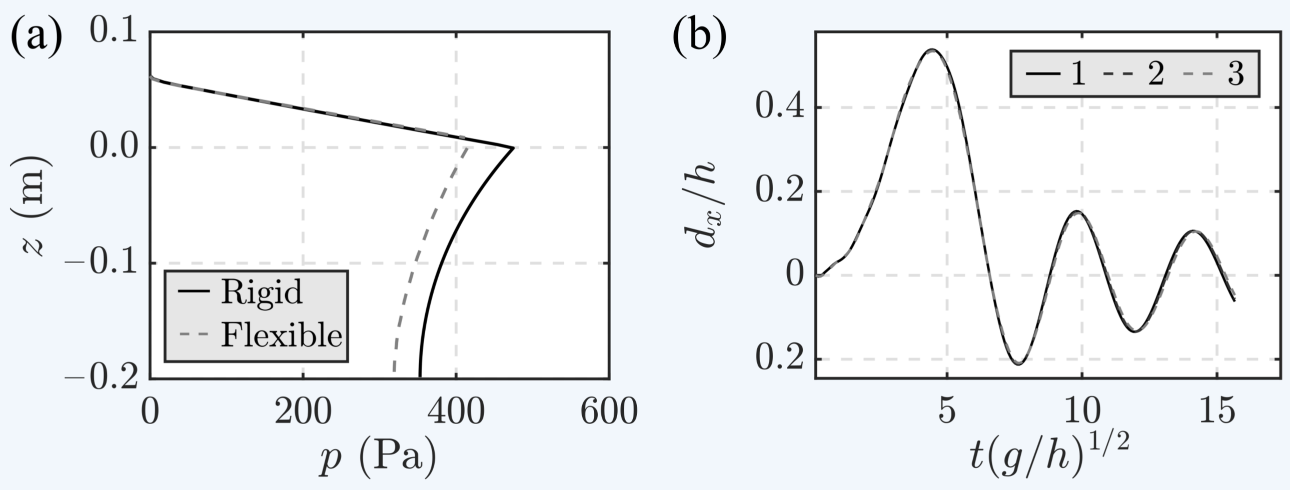

Fig. 7. Comparison of (a) $p(z)$ on rigid and flexible plates and (b) d_x/h for 3 experiments under conservation of $\Pi_{1,..,5}$.

4. Conclusions and Outlook

- The numerical toolbox **solids4foam** was successfully validated with available **laboratory** measurements, an **analytical** model and a **numerical** solution;
- **Tsunamis** impacting on **dams** were numerically investigated for a range of **wave conditions** and **dam inclinations**;
- The wave pressure on **flexible** plates is **smaller** than on **rigid** plates;
- The **governing parameters** for WSI were formulated and validated;
- Future work will enhance the **physical understanding**, support the **design** and optimise the experimental/numerical **modelling** of WSI.

References

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