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Dynamic Fluid-Structure Interaction: Exploring the Behavior of Flexible Beam

Wajiha Rehman
(University of Leeds / MARIN)

Dr. Tim Bunnik
(MARIN)

Outline

- Introduction
- Design of Experimental setup
- Experimental Case 1
- Experimental Case 2
- Experimental Case 3
- Data Availability
- Results & Conclusion

Introduction

Fluid Structure Interaction(FSI)

- Have you ever noticed how different types of fluids are interacting with solid structures around us? And realized how important these interactions are?

- Some of the many examples in nature are: leaves fluttering when wind flows, blood flowing in our body when the heart pumps, and the movement of fish in water as they flap their fins.

- In engineering: the movement of ship when the propeller rotates in water, movement of a suspended bridge when strong wind flows, and generation of power when water flows through a hydro-turbine.

Fluid Structure Interaction(FSI)

- Now that we realize the importance of fluid and solid interaction in our daily life. The questions are:
  - Do we fully understand the complexity of these interactions?
  - How do we scientifically study these phenomena that occur because of such interactions?
  - Can we explain these interactions with mathematical and numerical models?
- In this presentation, we will try to answer these questions.
- The study of interaction between fluid flow and solid structures is known as **fluid structure interaction** (FSI).
- FSI is a **multi-physics** problem which is an active area of research. Therefore, we still cannot fully comprehend the complex physics behind these interactions.

Maritime Industry

- In this presentation, we will experimentally study a FSI problem which can be of great significance in maritime industry.

- **Maritime industry** deals with the **transportation of goods and people** by sea, **production of seafood**, and **generation of energy**, e.g. offshore renewable energy devices and oil & gas extraction.

- Therefore, this **industry needs continuous technological advancement** to keep on supporting our society in an efficient way.

- The **common tools** which maritime industry uses for research and innovation are:
    - i. **experimental model testing**, and
    - **ii. mathematical** and **numerical modelling**.

Maritime Industry

- Maritime industry prefers mathematical and numerical modelling because this method is **cheaper** and **faster** than experimental scaled-model testing in wavetanks.

- However, numerical models require **validation** using **benchmark experimental data.**

- Hence, we conducted a series of **fluid-structure-interaction (FSI) experiments.**

- The aim is:
    - To **study the dynamic response of a flexible beam** exposed to a wide range of water-wave conditions.
    - Provide experimental data to validate FSI solvers employed by the maritime industry for the **design of fixed-foundation offshore wind turbines**.

Research facility

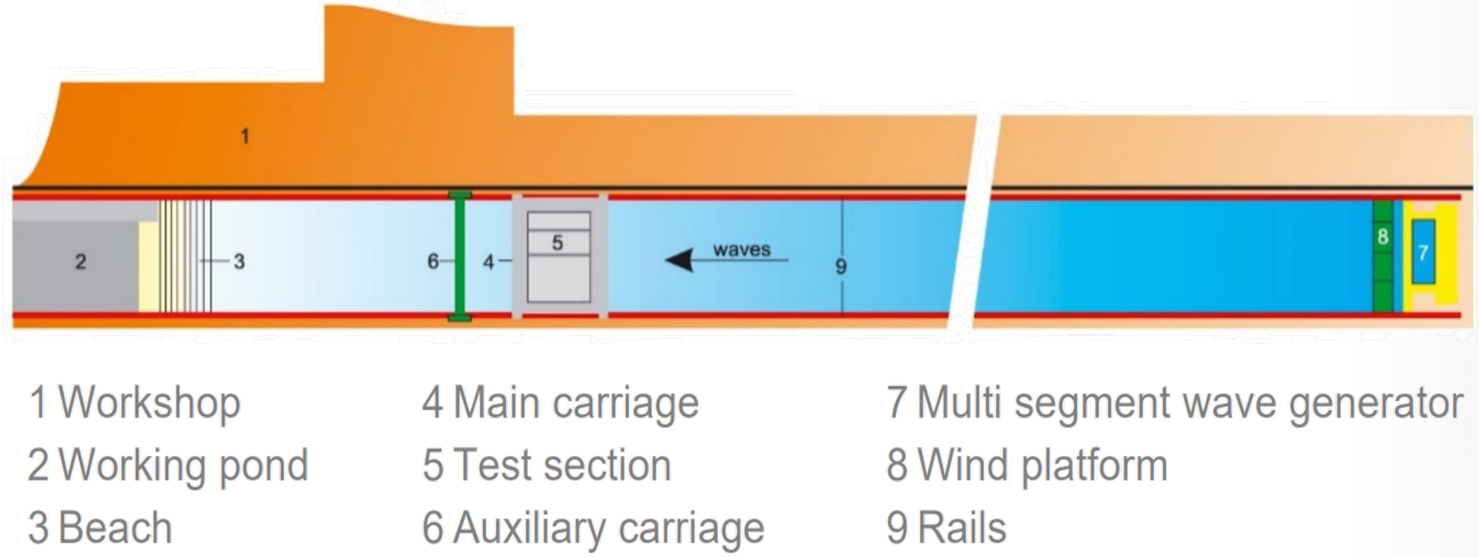

Fig 1: Schematic plan view of the concept wave basin at MARIN, The Netherlands [1].

<u>Specifications</u>

- Length: 220 m
- Width: 4 m
- Water depth: 3.6 m
- Wave-flap type wave generators

Design of Experimental Setup

Experimental setup

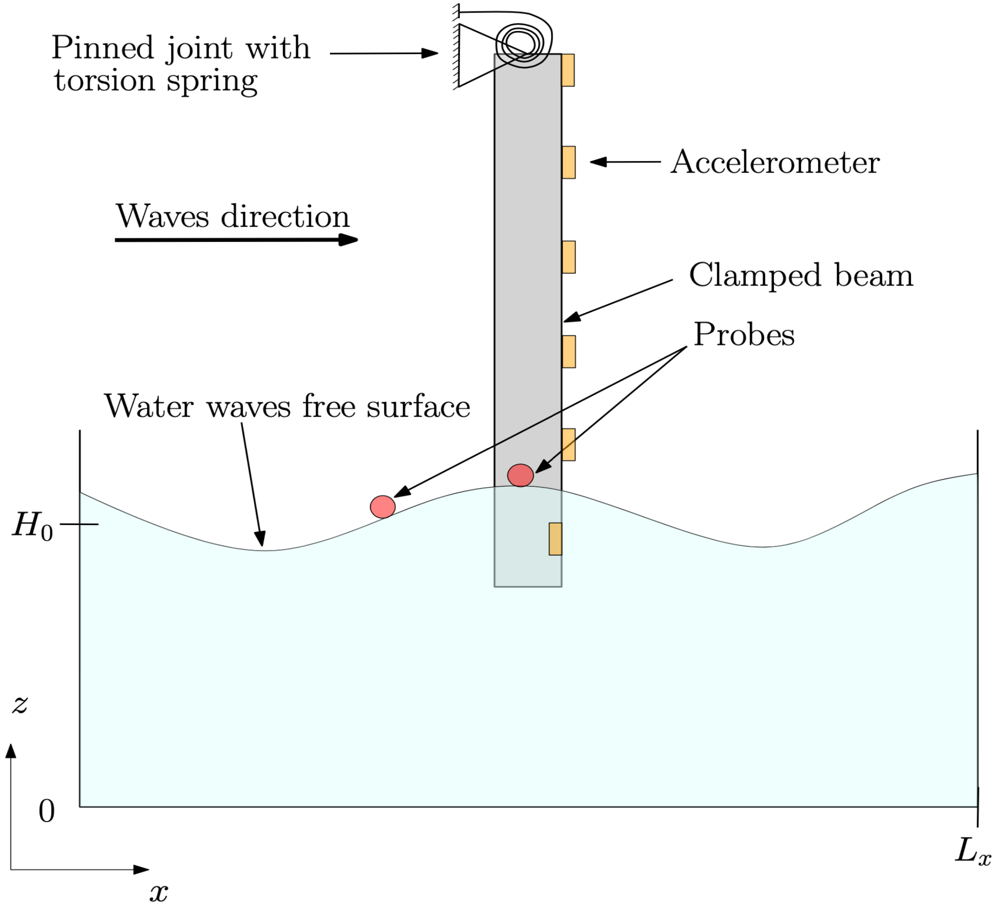

Fig 2: Schematic side view of the experimental setup.

- A partially submerged flexible beam is attached with the basin's carriage.
- Six accelerometers are placed equidistantly along the beam's length.
- A probe at the front of the beam to measure incident wave.
- A probe parallel to the beam to measure reflected waves.

Hammer tests

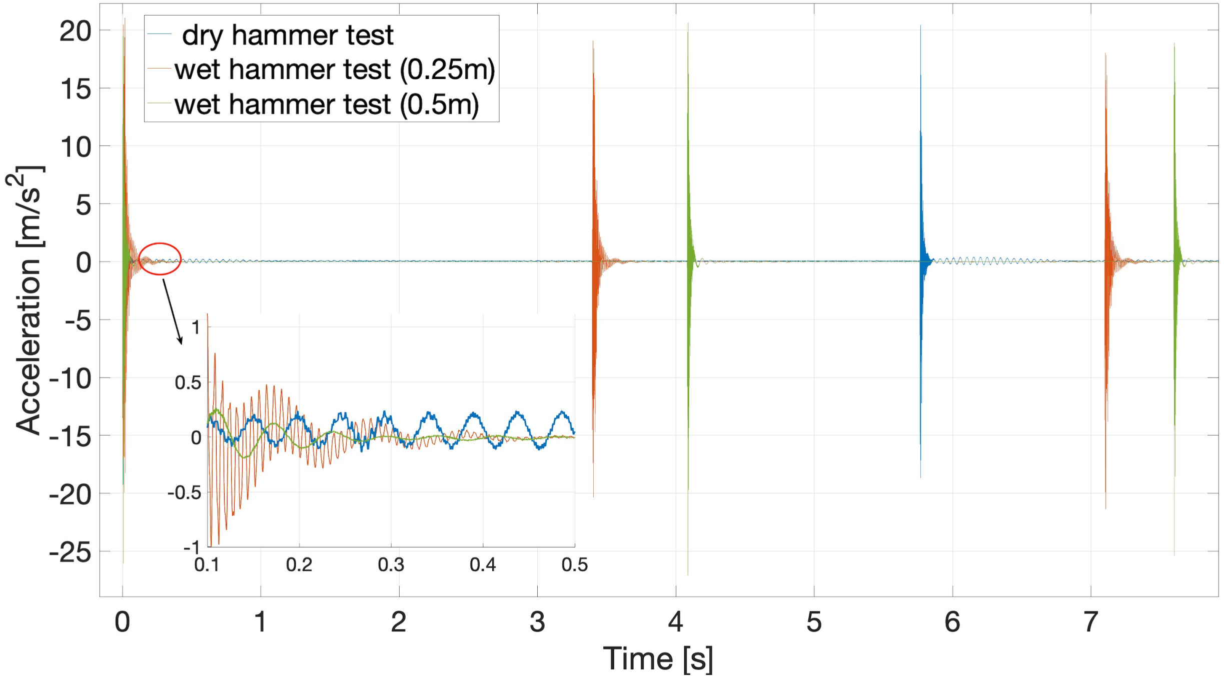

Fig 3: Time-domain beam responses (accelerations in x-direction) for the three hammer tests.

Table 1: Natural frequency and time period, measured in hammer tests, of the beam's first mode.

	Natural Period	**Natural Frequency**
	[s]	[s^{-1}]
Dry hammer test	0.299	3.34
Wet hammer test (0.25m)	0.48	2.08
Wet hammer test (0.5 m)	0.52	1.92

Experimental Case 1

Description

Fig 4: Generation of regular waves in MARIN's concept wave basin.(Photo courtesy of MARIN)

- The first case concerns the study of **interactions of regular waves with the flexible beam** when the **carriage is at rest.**
- The aim is to **validate linear FSI solvers in the non-resonant regime** as the non-linear dynamic response of beam is not excited by the incident-wave frequencies.
- This case is further divided into **two sub-cases corresponding to different submerged beam lengths** (0.25 m and 0.5 m).

Sub-cases of experimental case 1

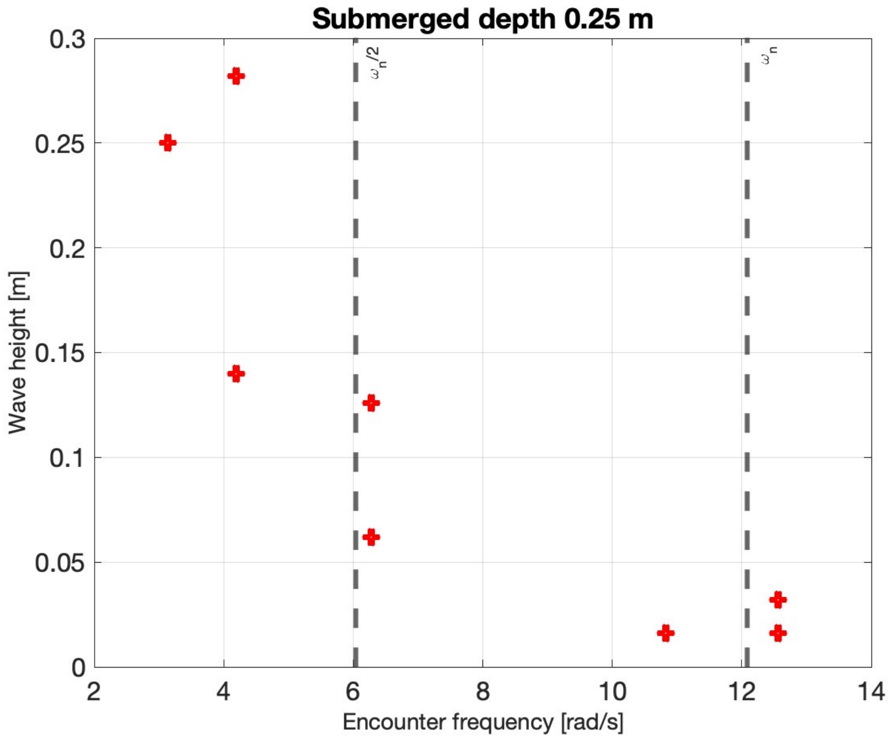

Fig 5: Incident-wave parameters compared to the beam's natural frequency when submerged depth is 0.25m.

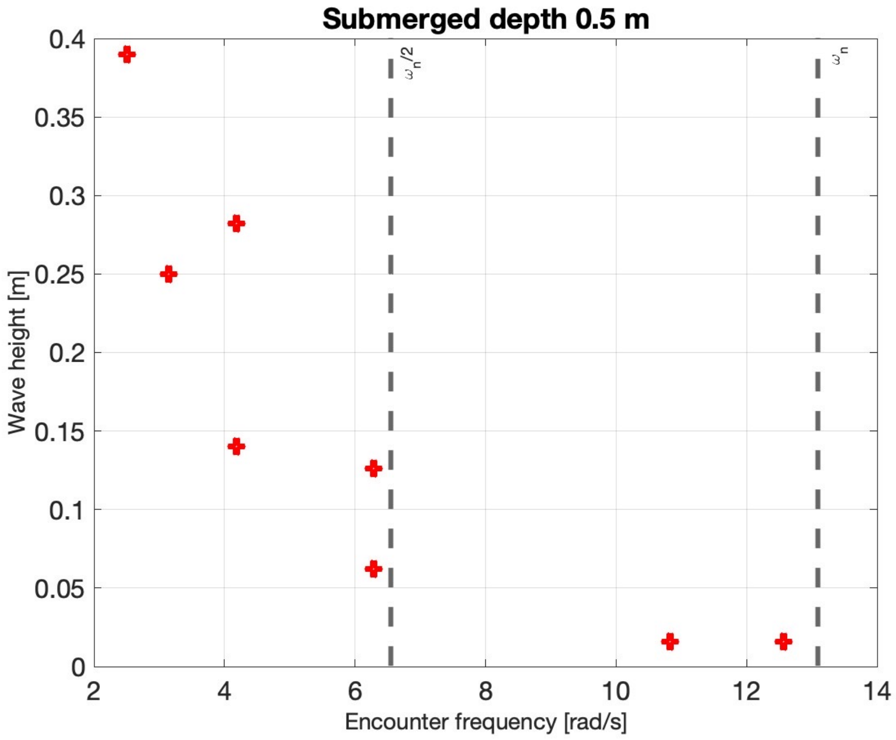

Fig 6: Incident-wave parameters compared to the beam's natural frequency when submerged depth is 0.5m.

Experimental Case 2

Description

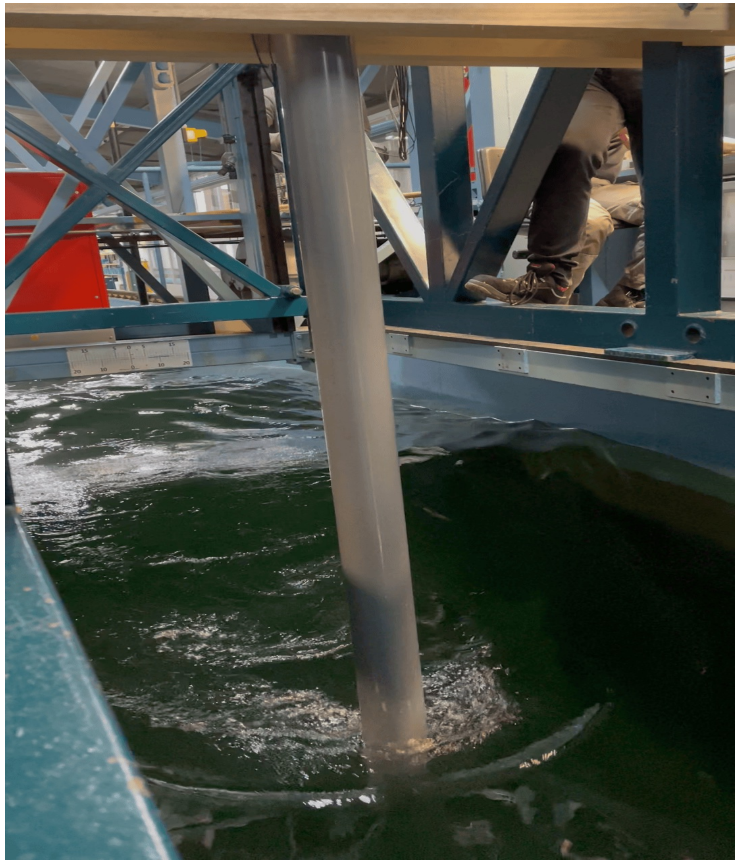

Fig 7: Interaction of water waves with the flexible beam.

- The second case concerns the study of **interactions of regular water waves with the flexible beam** when the **carriage is moving at a constant speed.**

- The aim is to study the **dynamic response of the beam** and its **interaction with water waves**, particularly at the onset of resonance.

- The data yielded by this study will help to **validate nonlinear FSI solvers.**

- This case is further divided into **two sub-cases corresponding to different submerged beam lengths** (0.25 m and 0.5 m).

Sub-cases of experimental case 2

Table 4: Regular-wave parameters and characteristics when the carriage is moving at a constant speed and **0.25m** of the beam is submerged in water

H	T	λ	H/λ	u_0	ω_e
[m]	[s]	[m]		[m/s]	[rad/s]
0.126	1	1.560	0.081	0.297	7.480
0.016	0.5	0.390	0.041	0.149	14.967
0.062	1	1.560	0.040	0.297	7.480
0.140	1.5	3.509	0.040	0.446	4.987

Table 5: Regular-wave parameters and characteristics when the carriage is moving at a constant speed and **0.5m** of the beam is submerged in water

H	T	λ	H/λ	u_0	ω_e
[m]	[s]	[m]		[m/s]	[rad/s]
0.126	1	1.560	0.081	-0.215	5.417
0.016	0.5	0.390	0.041	-0.108	10.831
0.062	1	1.560	0.040	-0.215	5.415
0.140	1.5	3.509	0.040	0.6864	5.418

Sub-cases of experimental case 2

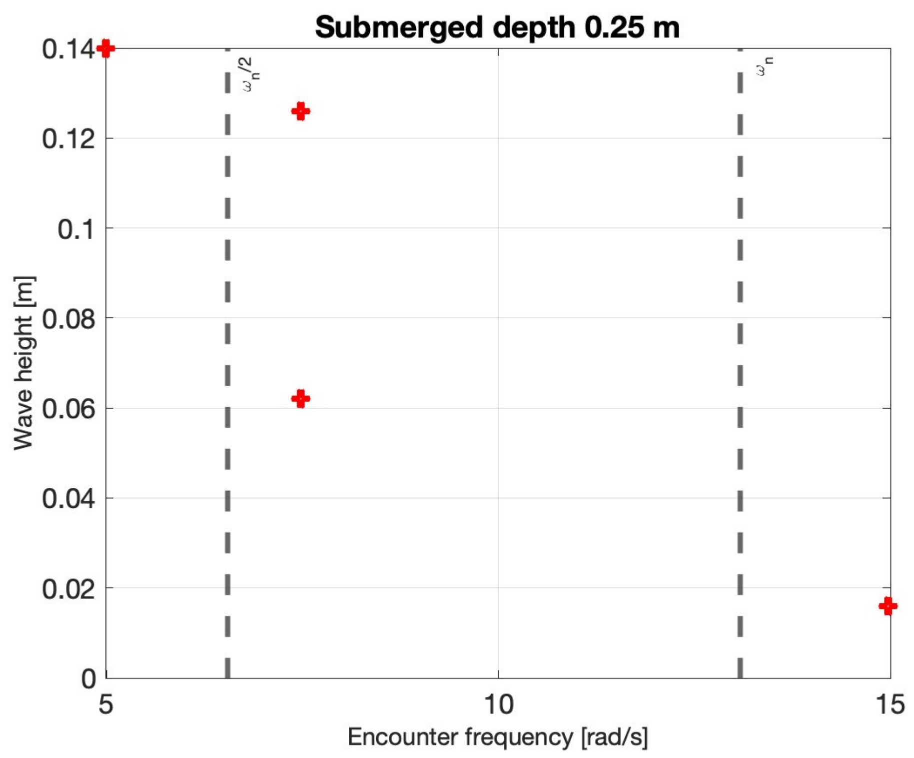

Fig 8: Incident wave frequency compared to the beam's natural frequency when submerged depth is 0.25m.

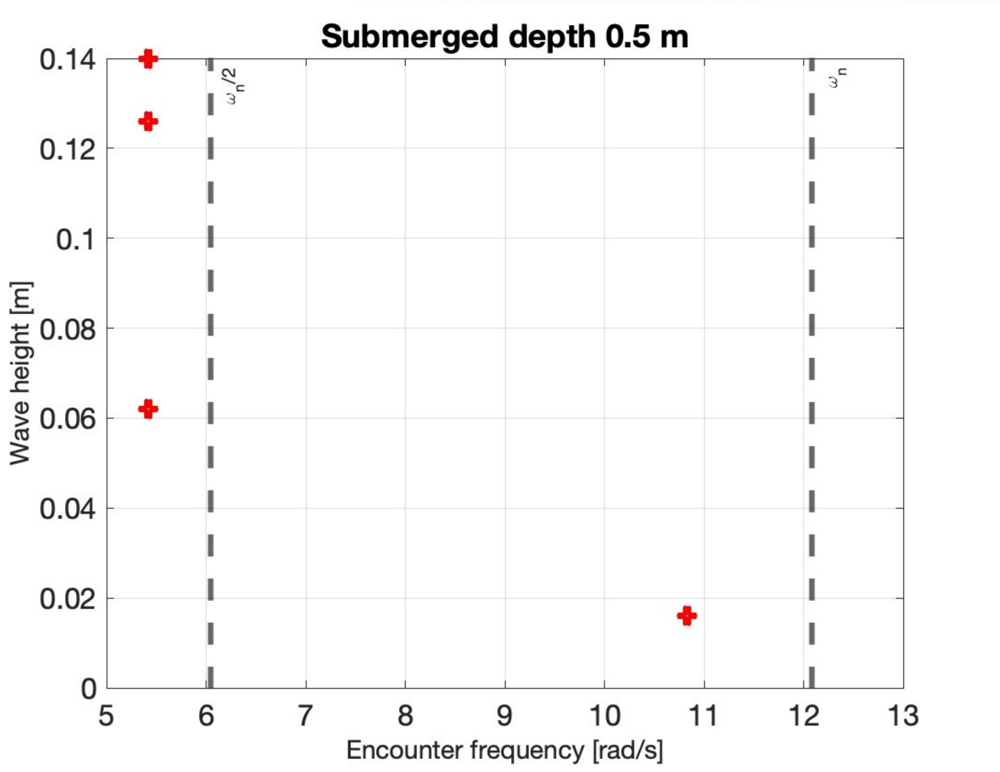

Fig 9: Incident wave frequency compared to the beam's natural frequency when submerged depth is 0.5m.

Experimental Case 3

Description

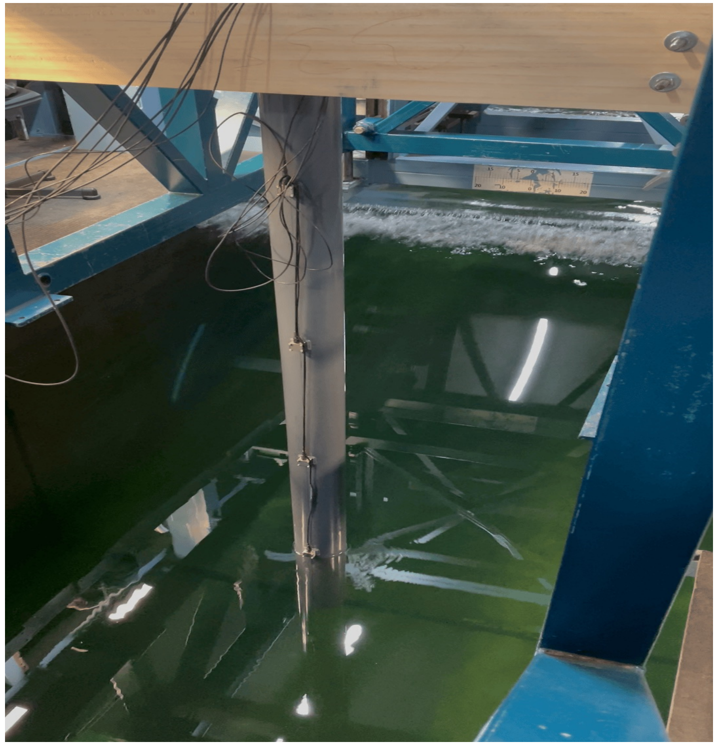

Fig 10: Interaction of steep water waves with the flexible beam.

- This case concerns **steep, irregular-wave interactions** with the **flexible beam** when the carriage is at rest.
- The aim is to **yield data on structural dynamics due to nonlinear wave-loading processes** related to steep and breaking waves.
- This case will help to **validate the high-fidelity FSI solvers.**
- This case is further divided into **two sub-cases corresponding to different submerged beam lengths** (0.25 m and 0.5 m).

Sub-cases of experimental case 3

Table 6: Irregular-wave parameters and characteristics when the carriage is at rest and 0.25m of the beam is submerged in water

MARIN test no. 70065_02CB_2	Environment	Time	Irregular sea characteristics			
			JONSWAP type spectrum			
			Hs	Tp	Dir.	gamma
		[s]	[m]	[s]	[deg]	[-]
North Sea state						
011_001_01	Gain 1.0	1781	0.340	2.25	180	2.9
011_001_01	Gain 0.25	1781	0.085	2.25	180	2.9
011_001_01	Gain 0.5	1781	0.170	2.25	180	2.9

Table 7: Irregular-wave parameters and characteristics when the carriage is at rest and 0.5m of the beam is submerged in water

MARIN test no. 70065_02CB_2	Environment	Time	Irregular sea characteristics			
			JONSWAP type spectrum			
			Hs	Tp	Dir.	gamma
		[s]	[m]	[s]	[deg]	[-]
North Sea state						
011_001_01	Gain 1.0	1781	0.34	2.25	180	2.9
011_001_01	Gain 0.5	1781	0.17	2.25	180	2.9

Data Availability

Data availability

- An open, public-access **GitHub repository*** has been created to share all experimental data.

- A **CAD drawing of the beam** and the **post-processing codes** are also shared with instructions.

- The data is organized into seven different folders:
    i. Folder **hammer_test**
    ii. Folder **Exp1_carriage_rest_0.25m**
    iii. Folder **Exp1_carriage_rest_0.5m**
    iv. Folder **Exp2_carriage_moving_0.25m**
    v. Folder **Exp2_carriage_moving_0.5m**
    vi. Folder **Exp3_irreg_waves_0.25m**
    vii. Folder **Exp3_irreg_waves_0.5m**

GitHub

* https://github.com/EAGRE-water-wave-impact-modelling/FSI_Experiments

Results & Conclusion

Interesting results

Fig 11: Experimental setup and interactions of regular waves with the flexible beam

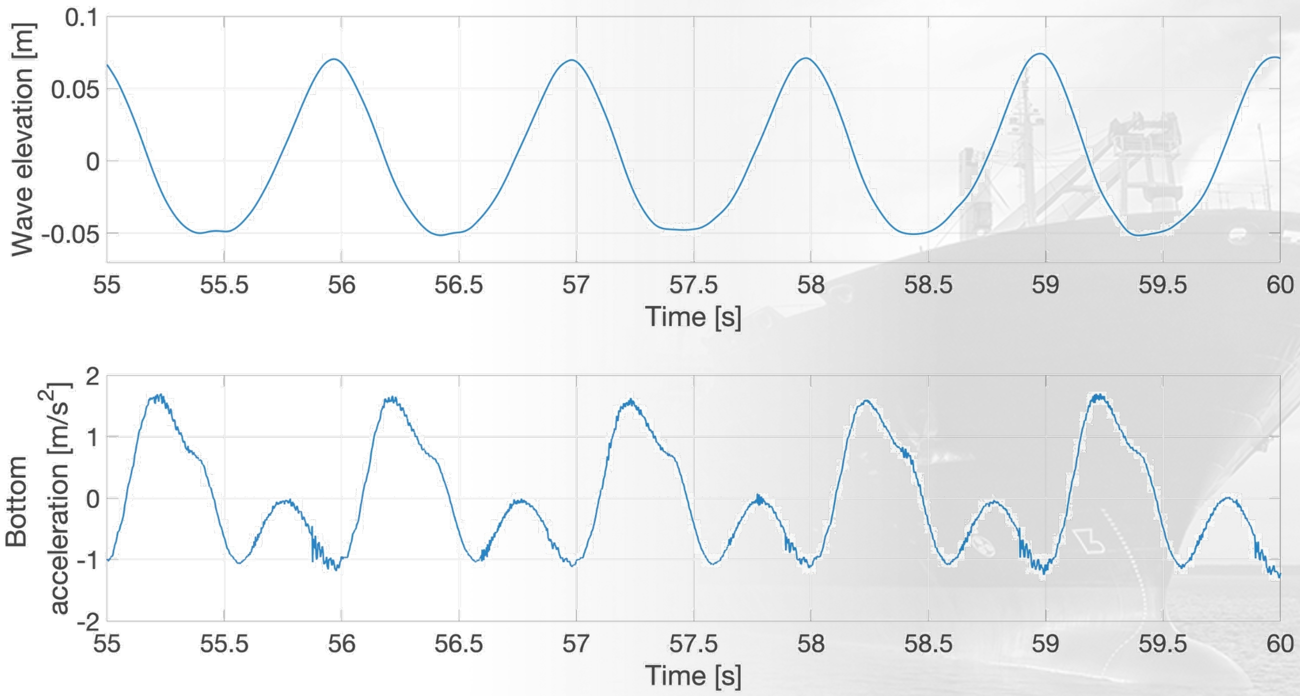

Fig 12: Response of the flexible beam to regular water waves

Interesting results

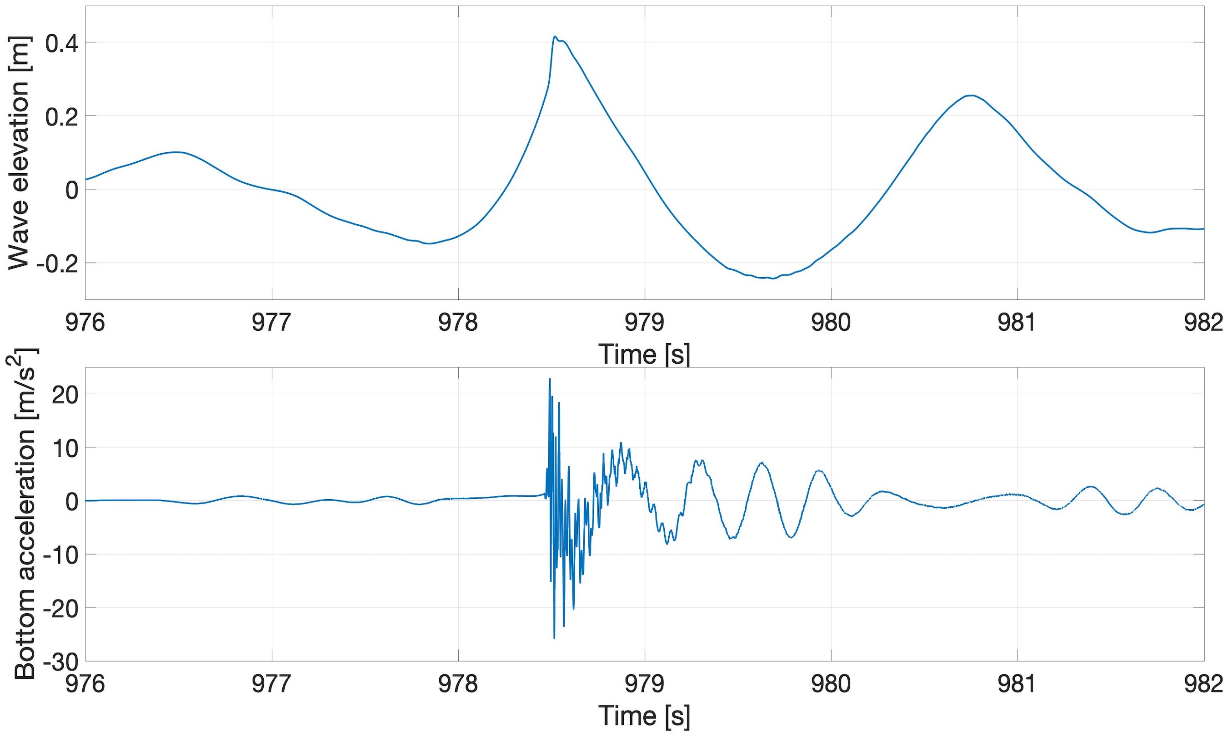

Fig 13: Response of the flexible beam to a steep irregular-wave.

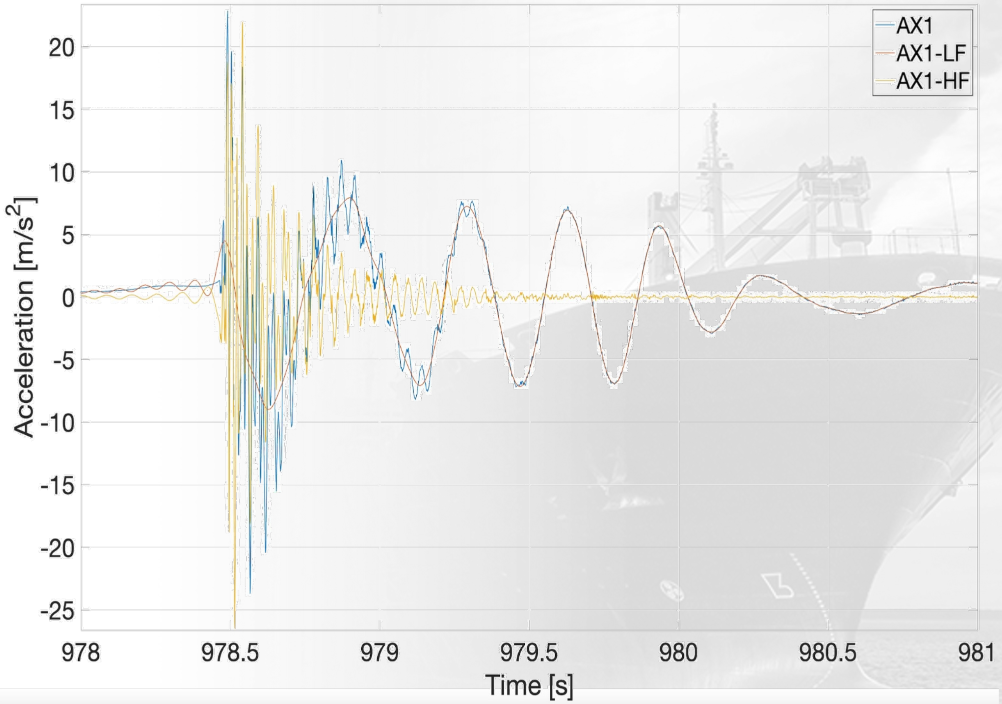

Fig 14: Frequency analysis of the response of the flexible beam to irregular waves. The **original signal** (blue) is decomposed into **higher** (yellow) and **lower** (red) frequency responses.

Conclusion

- The experimental campaign was successfully carried out and the **dynamic response of the flexible beam** was measured under a **wide range of wave conditions**

- **High-quality experimental data** is produced which is made **publicly accessible** through the GitHub repository

- A **comparison study** is being carried out at MARIN to **validate MARIN's FSI solvers** and the results obtained from the comparison will be presented in the future in the form of research articles

References

1. MARIN concept basin. file:///Users/mmwr/Downloads/Concept_Basin.pdf. Accessed: 19-11-2022.

Thank you!