Fluid Force Identification

A method to Predict Wear of a Control Rod in a Nuclear Power Plant

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Contents

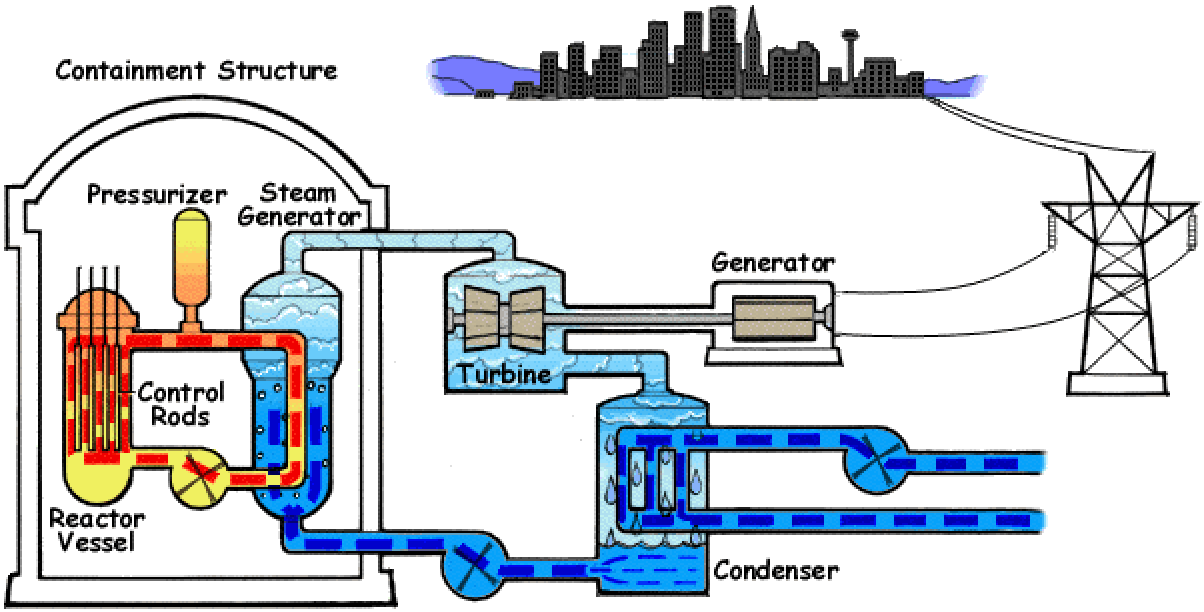
Introduction

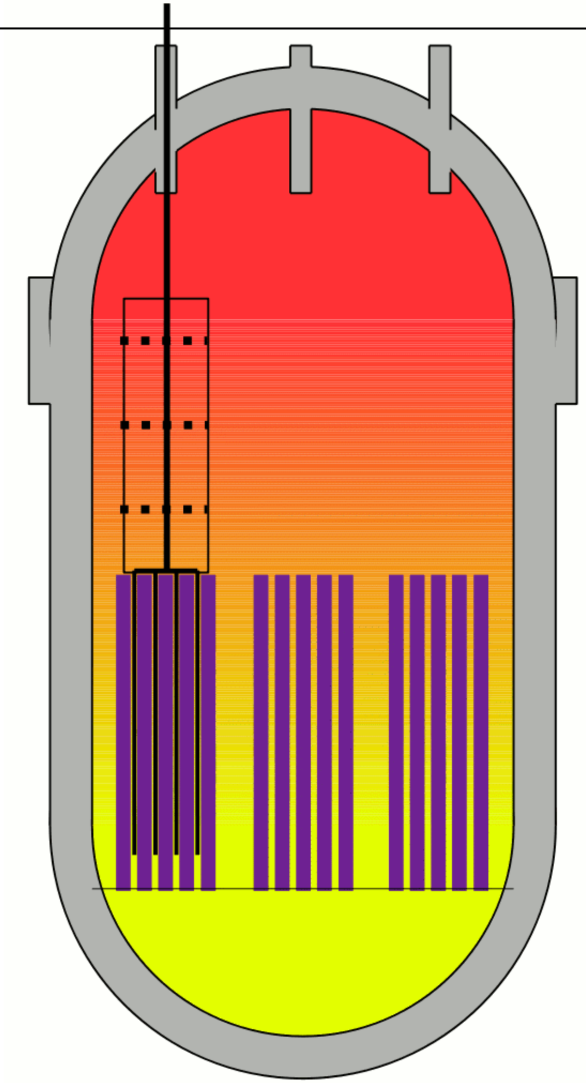
Increasing demand for Nuclear Power

EDF operates 53 Nuclear Power Plants in France alone

Presurized Water Reactors vs Boiling Water Reactors

New design: European Pressurized Reactor (EPR)


Containment Structure
Pressurizer
Steam Generator
Generator
Control Rods
Turbine
Reactor Vessel
Condenser



Introduction

Problem

The Spider with the Control Rods is extended from the Fuel Rod Assembly when in Operation

The Control Rods are Guided by Guide-plates

The Fluid Flow Induces a Vibration on the Control Rod

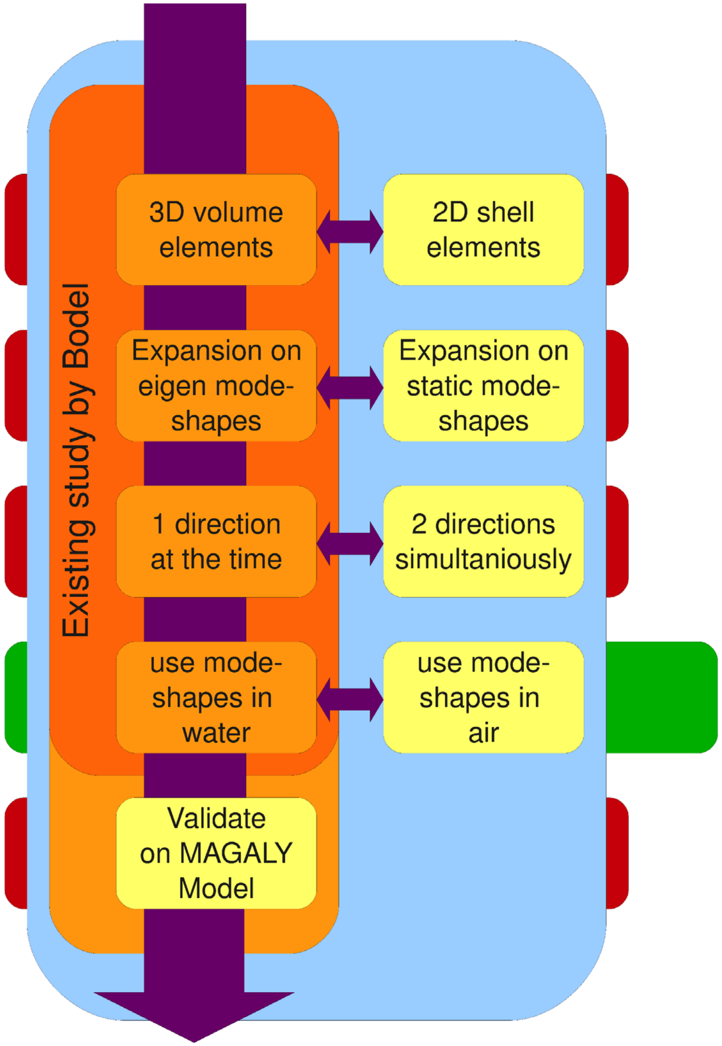
The Control Rods Wear out at the Guide-plates

Research Objective

'A Method to Model the Fluid Flow and to Predict the Wear of the Control Rods'

Method is initiated by Bodel in 2008

My Task: To Verify and Validate this Method



Comparison of Numerical Models

Static shapes as Expansion space

Mode-shapes in 2D

Different Mode-shapes to model system

Validation

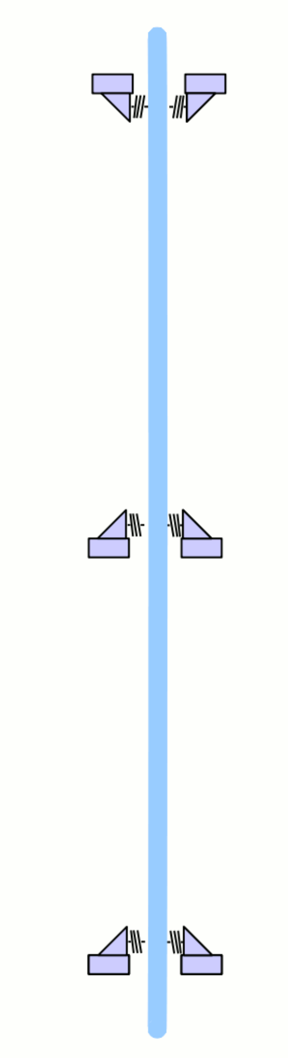
Research Objective

Theory

Modal Analysis

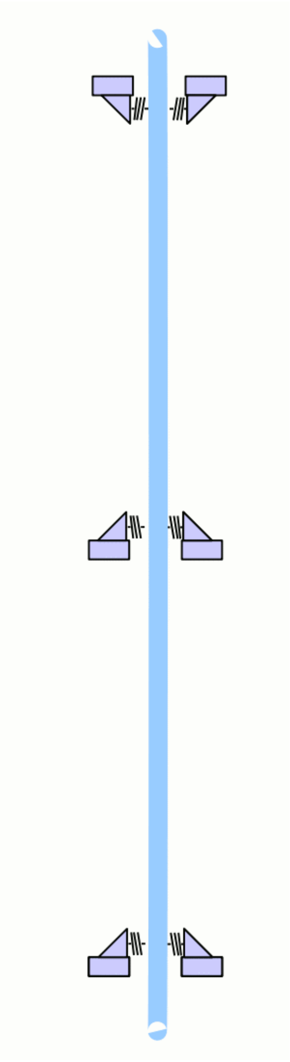
Fluid Force Modelling

Modal Analysis



Theory

Modal Analysis



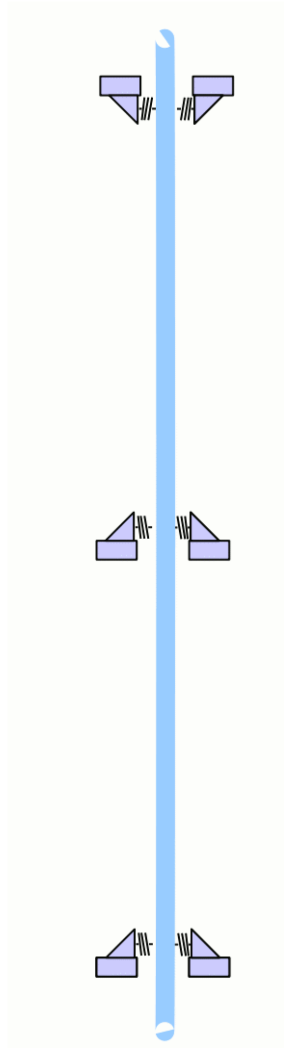
First Mode-shape f_1

Frequency $w_1 = 2$? [rad/s]

Theory

Modal Analysis

TU Delft



Second Mode-shape f_2

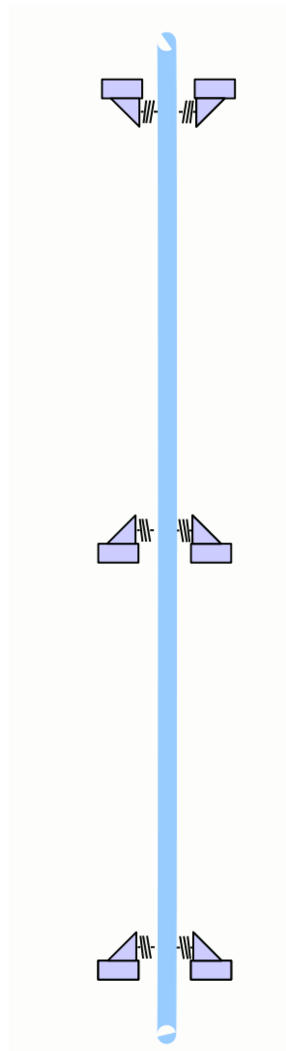
Frequency w_2 = 4□ [rad/s]

Theory

eDF

Modal Analysis

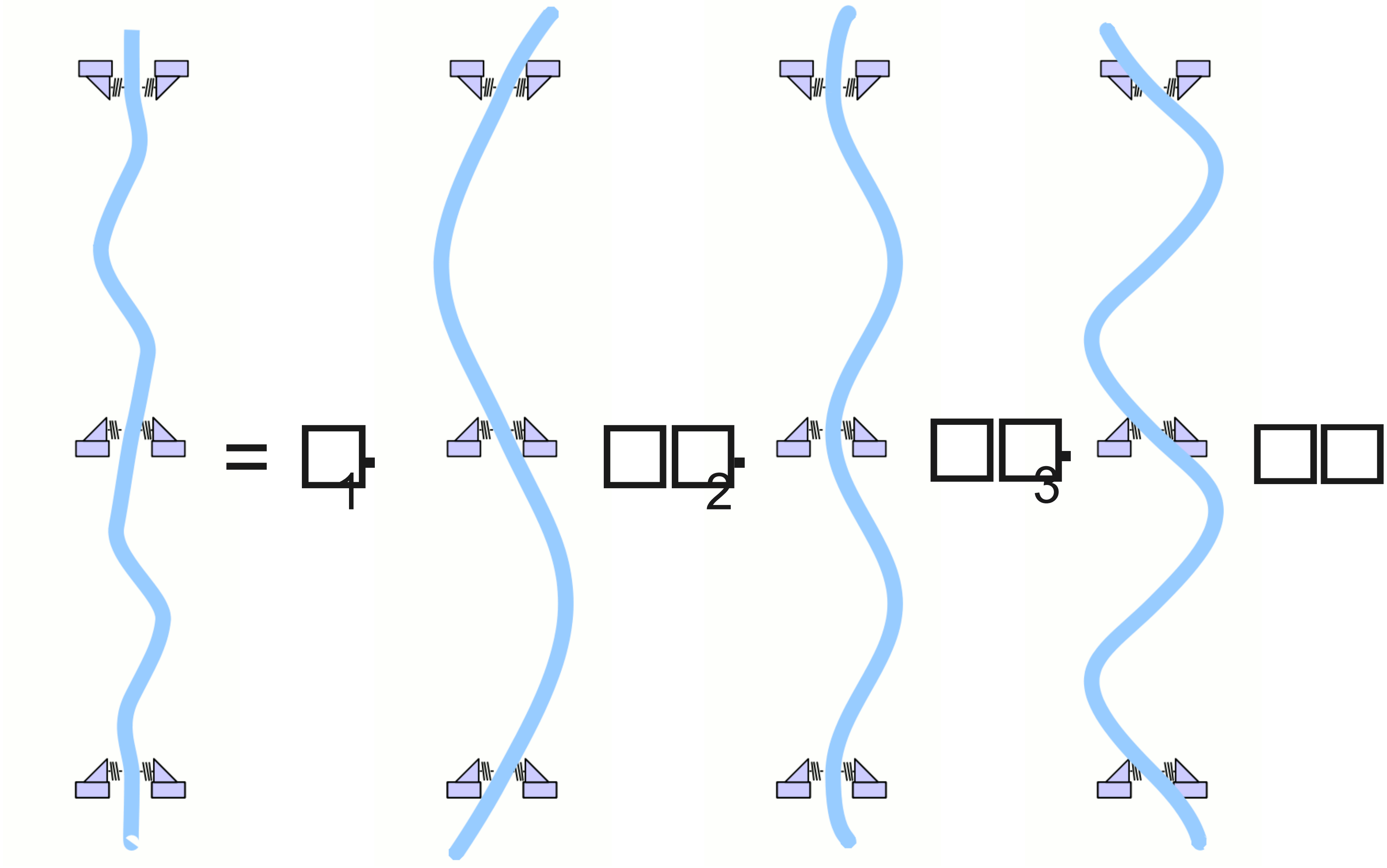
TU Delft



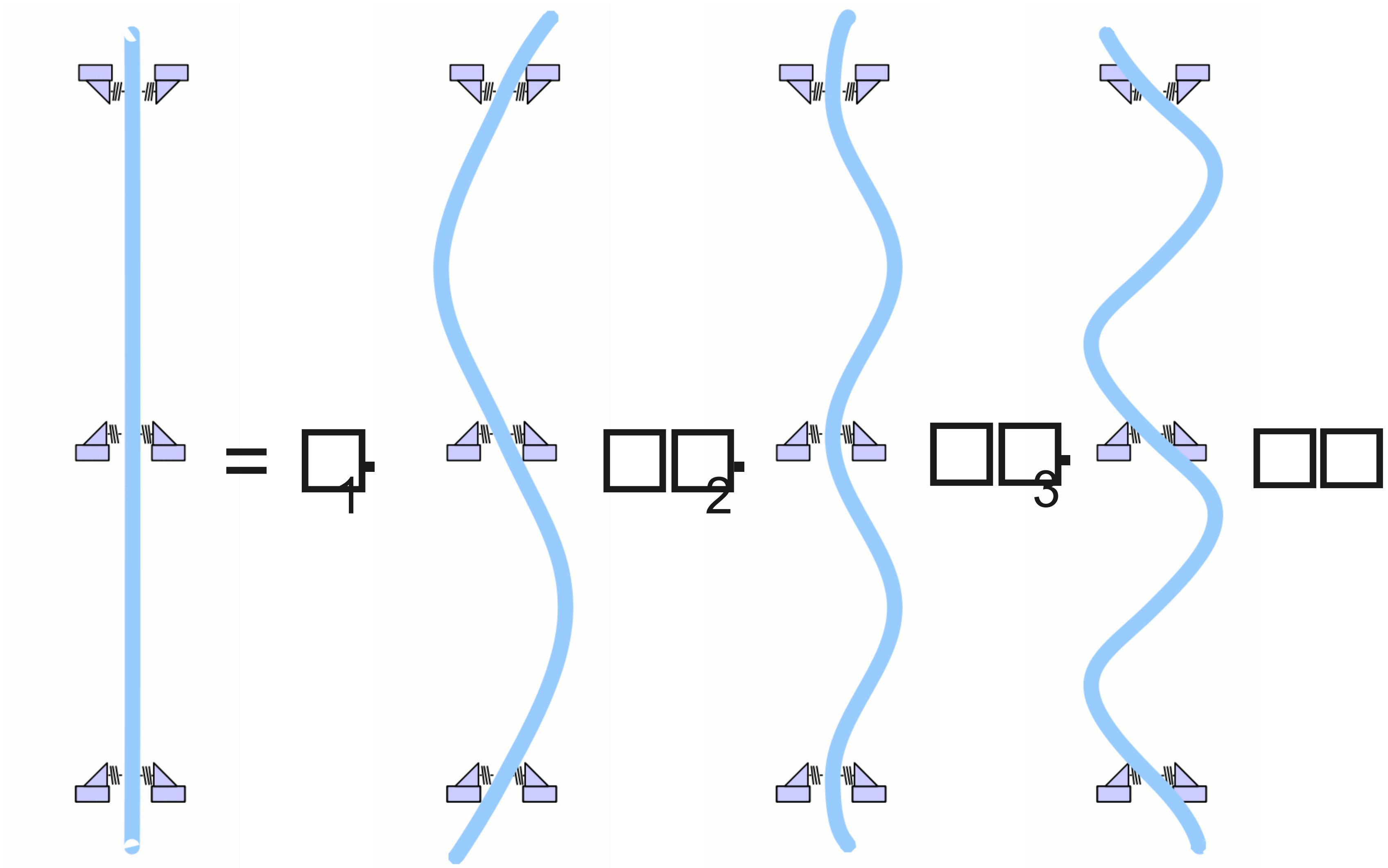
Third Mode-shape f_3

Frequency $w_3 = 6$□ [rad/s]

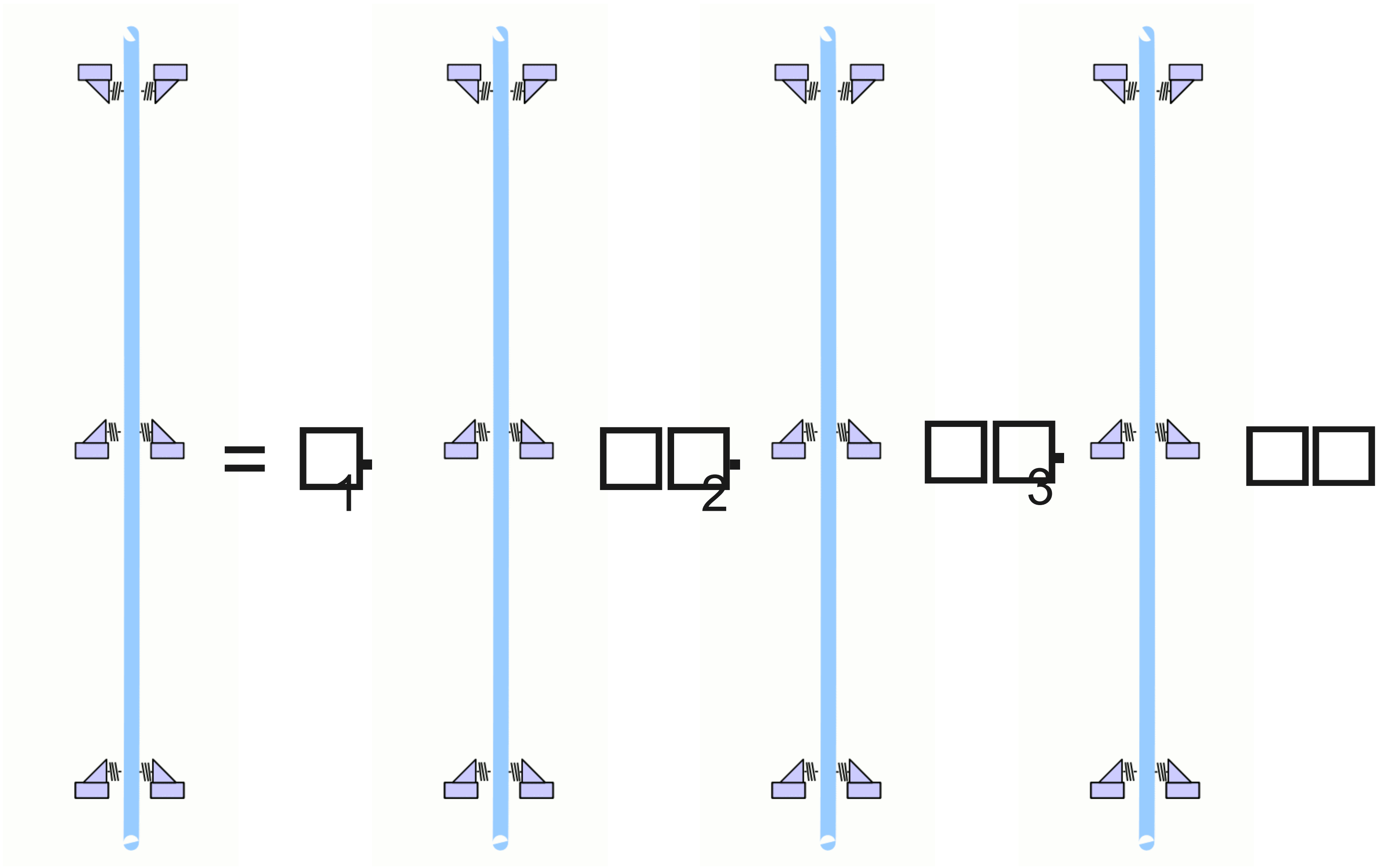
Modal Analysis



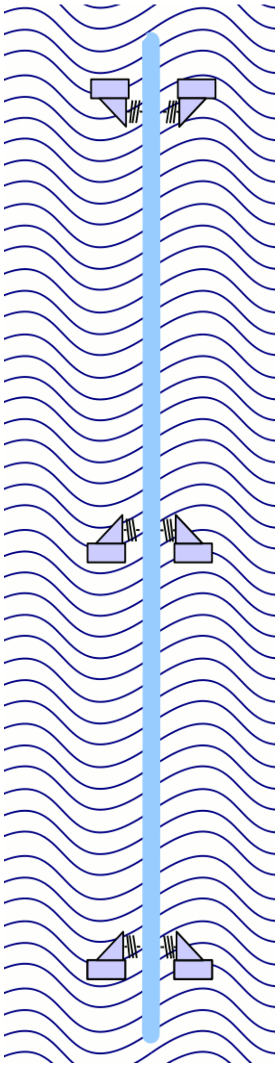
Modal Analysis



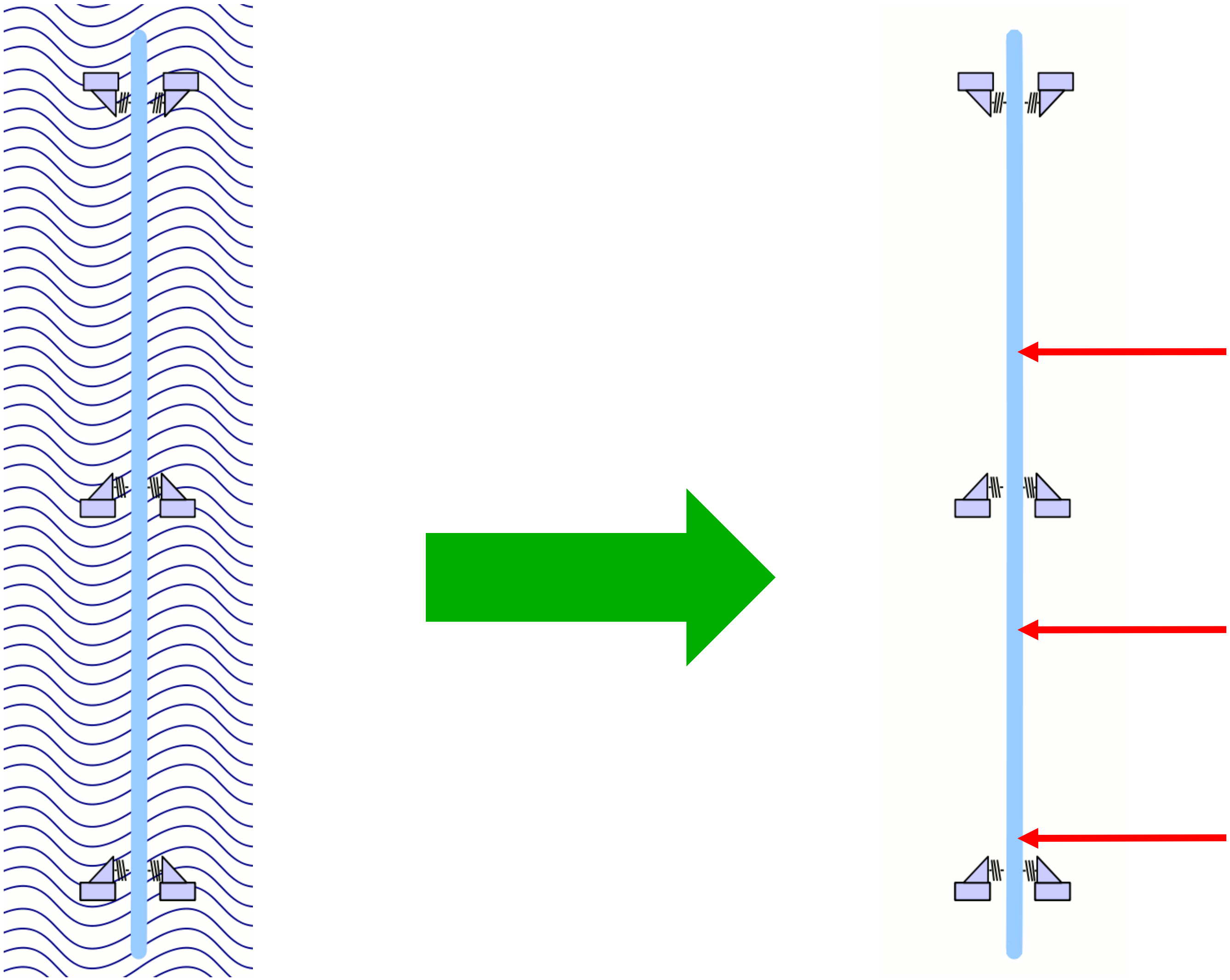
Modal Analysis



Modelling the Fluid Force

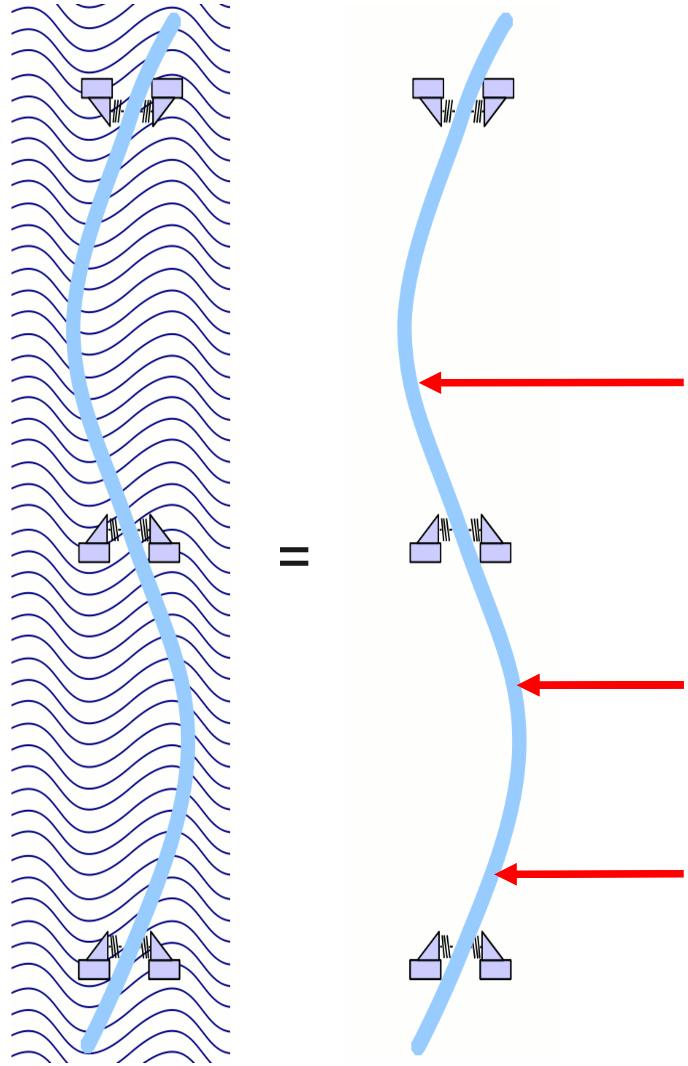


Modelling the Fluid Force



Modelling the Fluid Force

$$\square_1 = \frac{\square_1^T \cdot f_{water}}{m_1 \square \square^2 \square\square_1^2 \square} =$$

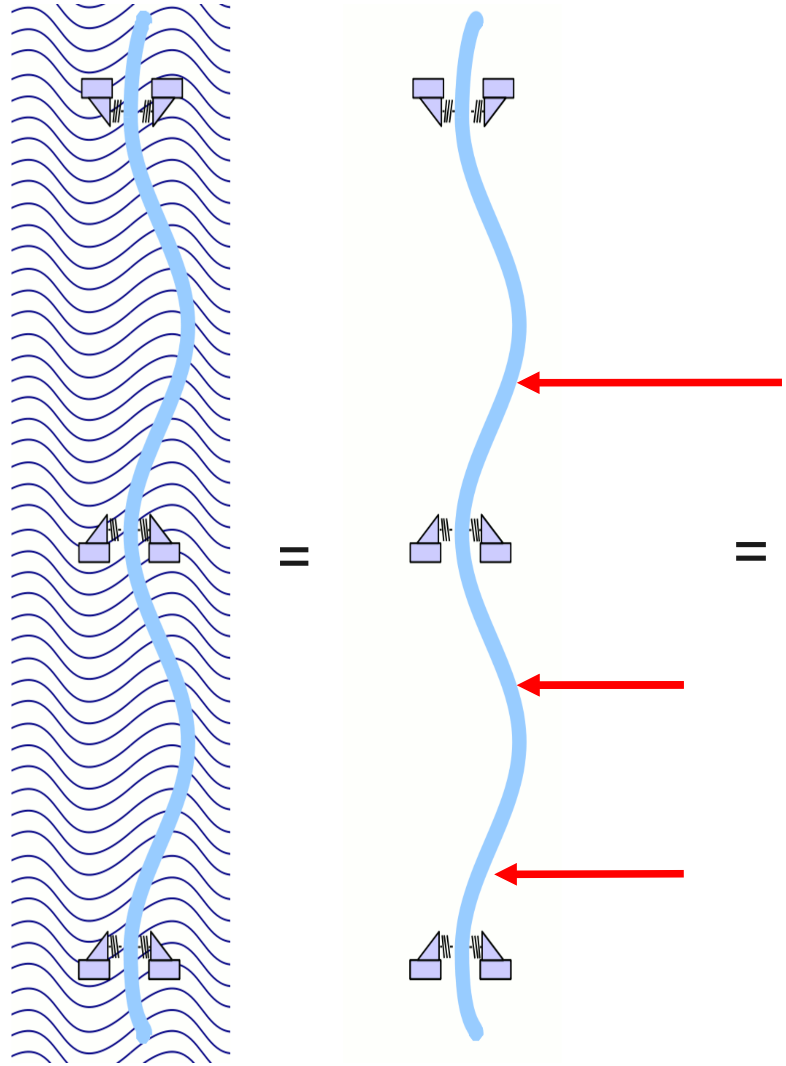


$$= \quad = \frac{\square_1^T \cdot B \cdot f_{point}}{m_1 \square \square^2 \square\square_1^2 \square}$$

eDF

Modelling the Fluid Force

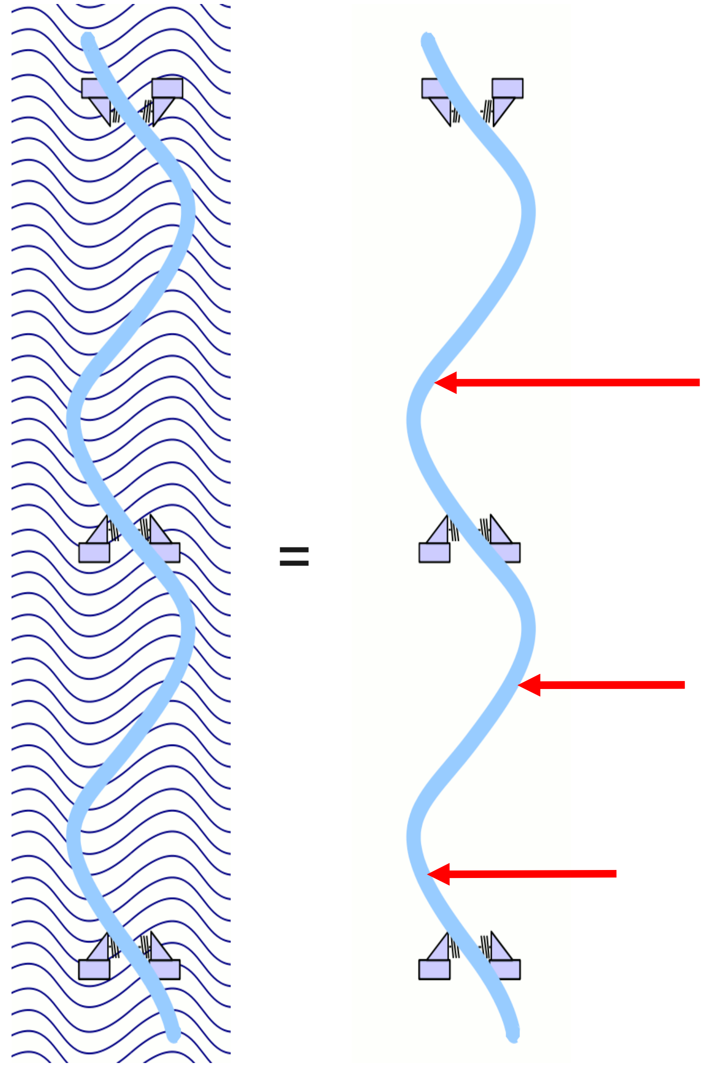
$$\square_2 = \frac{\square_2^T \cdot f_{water}}{m_2 \boxminus \square^2 \square \square_2^2 \square} =$$



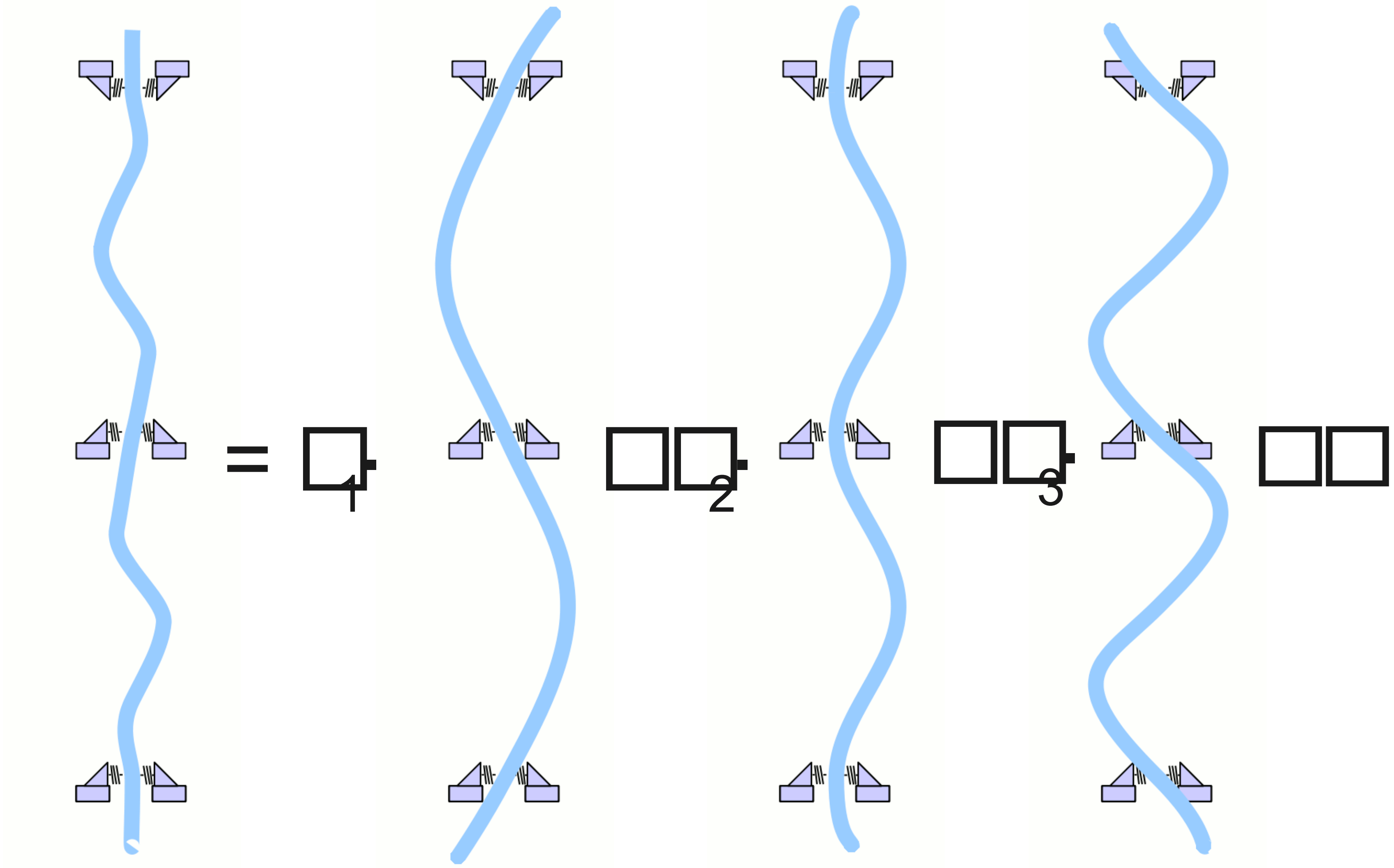
$$= \frac{\square_2^T \cdot B \cdot f_{point}}{m_2 \boxminus \square^2 \square \square_2^2 \square}$$

Modelling the Fluid Force

$$\square_3 = \frac{\square_3^T \cdot f_{water}}{m_3 \left[- \square^2 \square \square_3^2 \square \right]} = $$

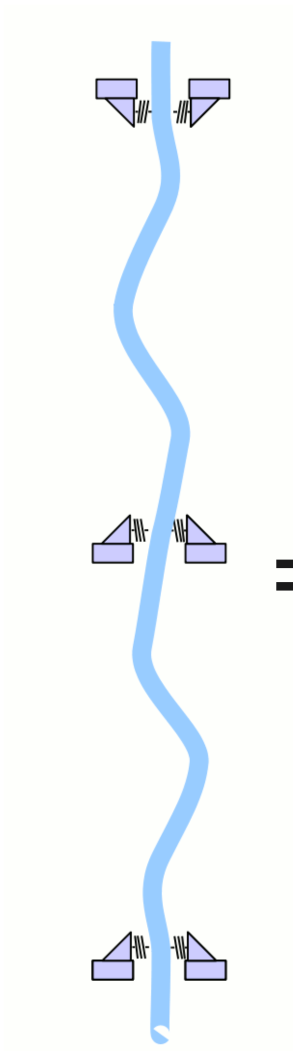


$$= \frac{\square_3^T \cdot B \cdot f_{point}}{m_3 \left[- \square^2 \square \square_3^2 \square \right]}$$



=
1
2
3

Transfer Function



$$= \sum_i \frac{\square_i \square_i^T}{m_i \square \square^2 \square \square \square_i^2 \square} B f_{point}$$

The Method

Model the System in Water using Mode-shapes...

$$\sum_i \frac{\square_i \square_i^T}{m_i \square \square^2 \square \square_i^2 \square}$$

...and use this System to calculate the Point Forces.

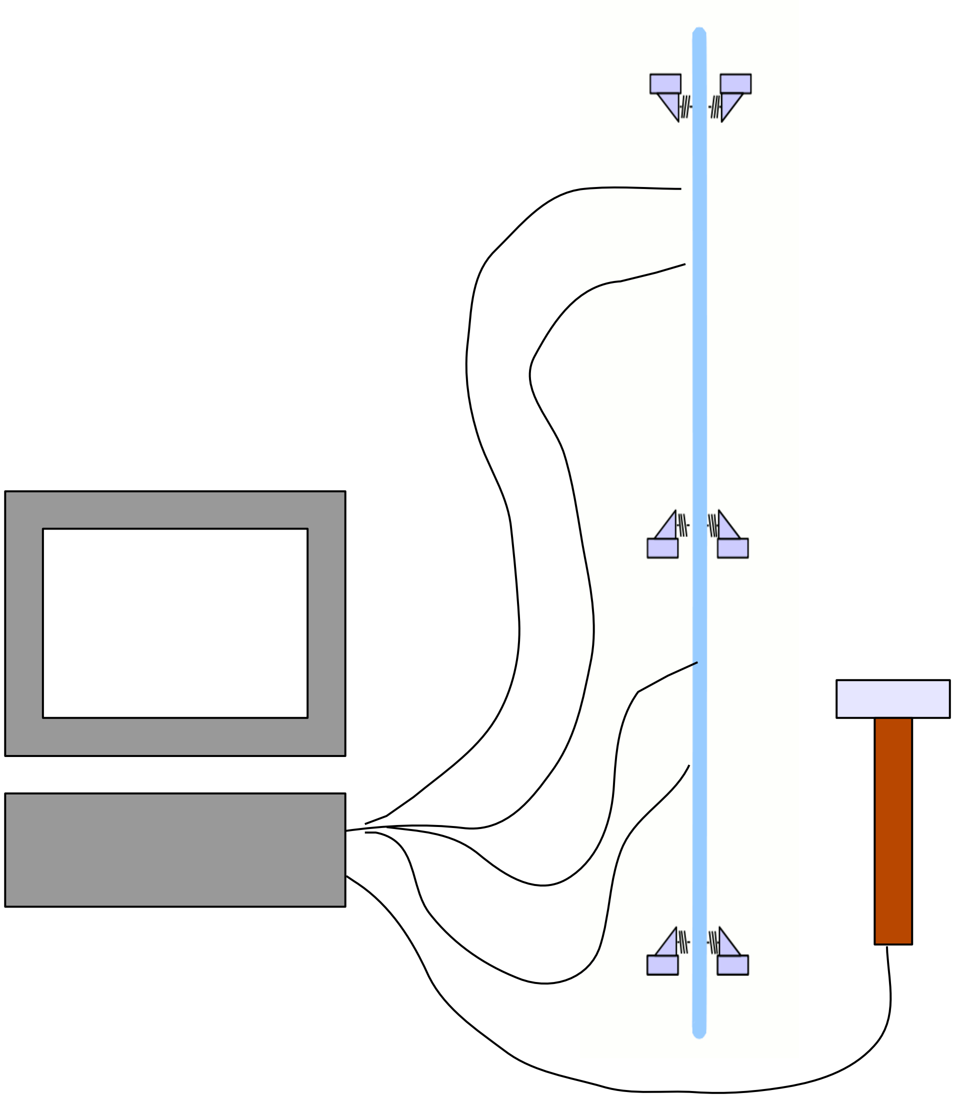
$$f_{point}$$

The Study

Obtain Experimental Mode-shapes

Mass Normalize the Mode-shapes

Identify the Fluid Force



Hammer excitation

Measure the input and output signal

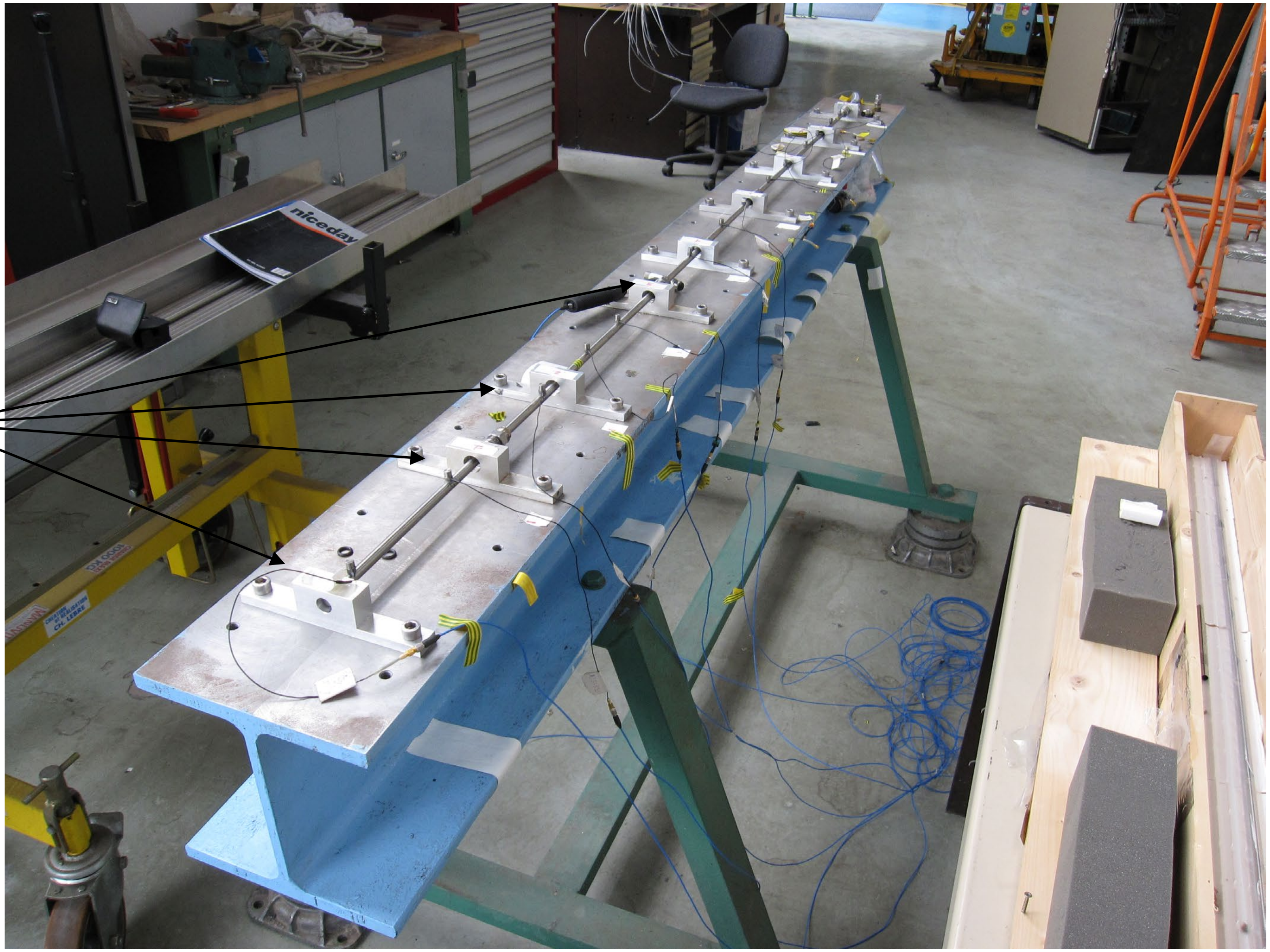
$$x=\sum_i \frac{\phi_i \phi_i^T}{m_i\left(-\omega^2+\omega_i^2\right)} \cdot f_{hammer}$$

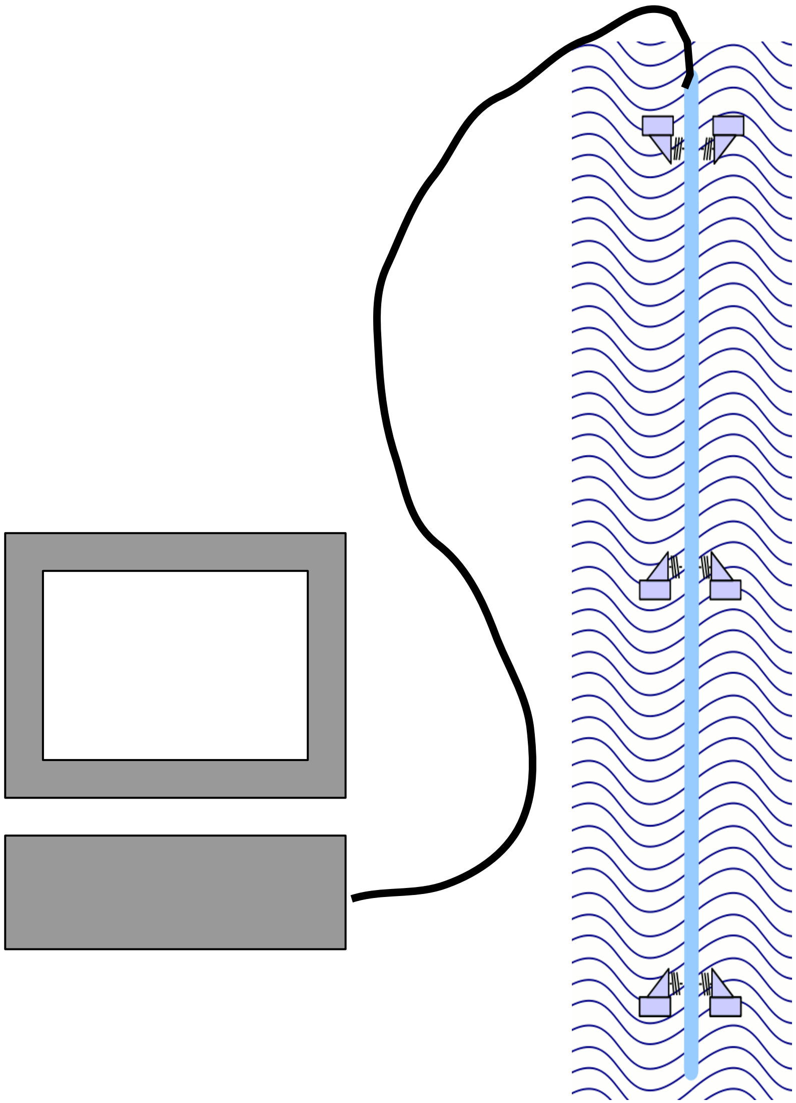
Mass Normalize the Mode-shapes

Practice

The Phacetie Model

Modelled
guide-plates





Strain gauges inside the tube

Measure only the output signal

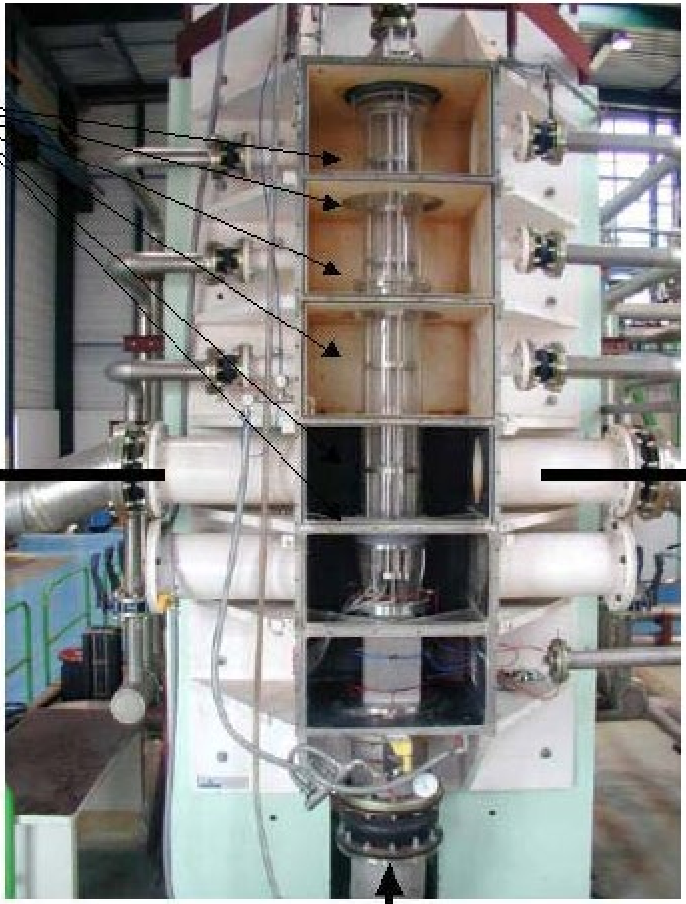
$$x=\sum_i \frac{\phi_i \phi_i^T}{m_i\left(-\omega^2+\omega_i^2\right)} \cdot f_{water}$$

No Normalized Mode-shapes

The Phacetie Model

Modelled guide-plates

Water outlet nozzle



Water outlet nozzle

Water inlet nozzle

Non-normalised Mode-shapes of the system in Water

Mass Normalised Mode-shapes of the system in Air

Frequency difference between Water and Air

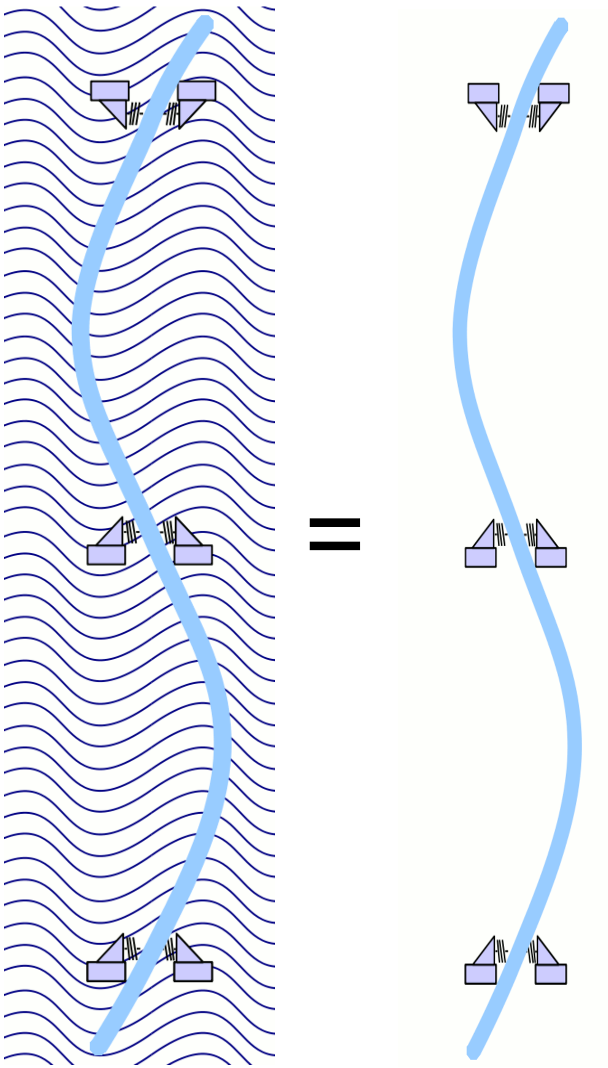
The Study

Obtain Experimental Mode-shapes

Mass Normalize the Mode-shapes

Identify the Fluid Force

Assumptions



$w_{air} > w_{water}$

Modal mass

Mass Normalize the Mode-shapes

Method I

$$k_{water,i} = k_{air,i}$$

$$\square_{water,i} = C_i \, \square_{air,i}$$

$$\square\square_i = \square_{air,i} - \square_{water,i}$$

$$\square_i = \sqrt{\frac{k_i}{m_i}}$$

$$m_{water,i} = m_{air,i} \, \square \, m_{added,i}$$

$$m_{air,i} = \square A \int \square^2_{air,i}$$

$$m_{water,i} = m_{air,i} \frac{\square^2_{air,i}}{\square^2_{water,i}} \frac{\int \square^2_{water,i}}{\int \square^2_{air,i}}$$

$$\square_{water,i} = \frac{\square_{water,i}}{\sqrt{m_{water,i}}}$$

For each mode $i = 1, 2, 3, \ldots, n$

The Study

Obtain Experimental Mode-shapes

Mass Normalize the Mode-shapes

Identify the Fluid Force

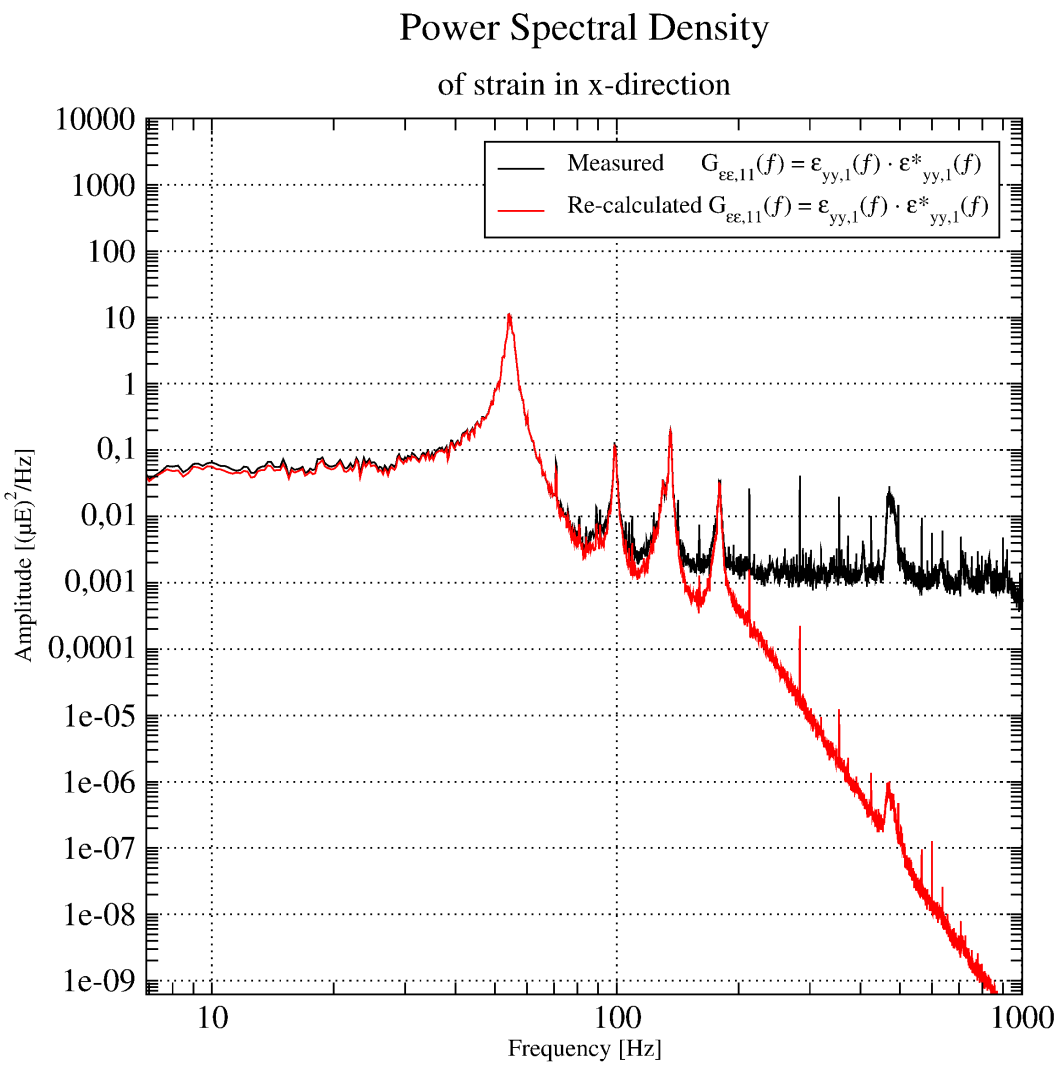
Identifying the Forces

$$x_{measured} = [\sum_i \frac{C \square_i \square_i^T B}{m_i \boxminus \square^2 \square \square_i^2 \square}] f_{point}$$

Identify the Point Forces by Inverting the Transfer Function using a Pseudo Inverse

$$f_{point} = [\sum_i \frac{C \square_i \square_i^T B}{m_i \boxminus \square^2 \square \square_i^2 \square}]^{\square} x_{measured}$$

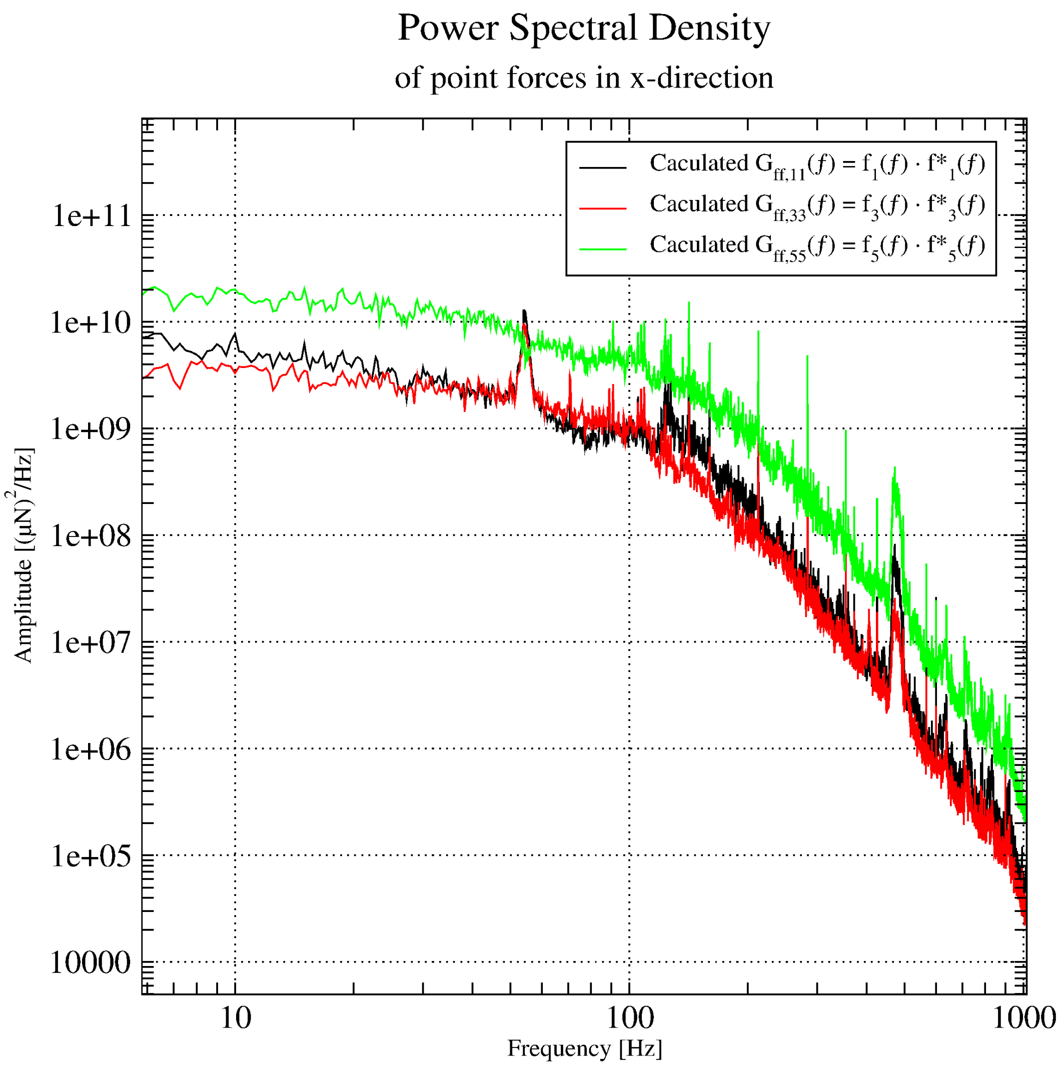
Results Method I



Measured and Re-calculated

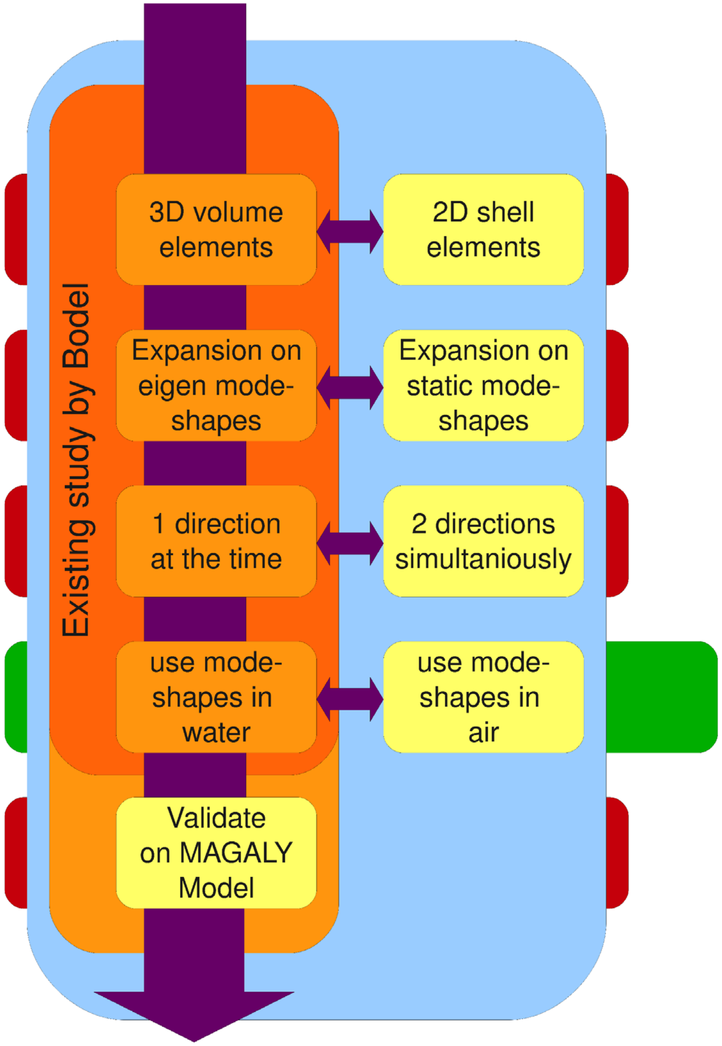
Modelling the system using the Mass normalised Mode-shapes in Water

Results Method I



Calculated Point Forces

Modelling the system using the Mass normalised Mode-shapes in Water



Different mode-shapes to model system

Modelling the System

I Using the Mode-shapes obtained in Water (Mass Normalised)

II Using the Mode-shapes obtained in Air (Re-normalised)

Method I

$$k_{water,i} = k_{air,i}$$

$$\square_{water,i} = C_i \, \square_{air,i}$$

$$\square\square_i = \square_{air,i} - \square_{water,i}$$

$$\square_i = \sqrt{\frac{k_i}{m_i}}$$

$$m_{water,i} = m_{air,i} \square m_{added,i}$$

$$m_{air,i} = \square A \int \square^2_{air,i}$$

$$m_{water,i} = m_{air,i} \frac{\square^2_{air,i}}{\square^2_{water,i}} \frac{\int \square^2_{water,i}}{\int \square^2_{air,i}}$$

$$\square_{water,i} = \frac{\square_{water,i}}{\sqrt{m_{water,i}}}$$

For each mode $i = 1, 2, 3, \ldots, n$

Method II

$$k_{water,i} = k_{air,i}$$

$$\square_{water,i} = C_i \, \square_{air,i}$$

$$\square\square_i = \square_{air,i} - \square_{water,i}$$

$$\square_i = \sqrt{\frac{k_i}{m_i}}$$

$$m_{water,i} = m_{air,i} \, \square \, m_{added,i}$$

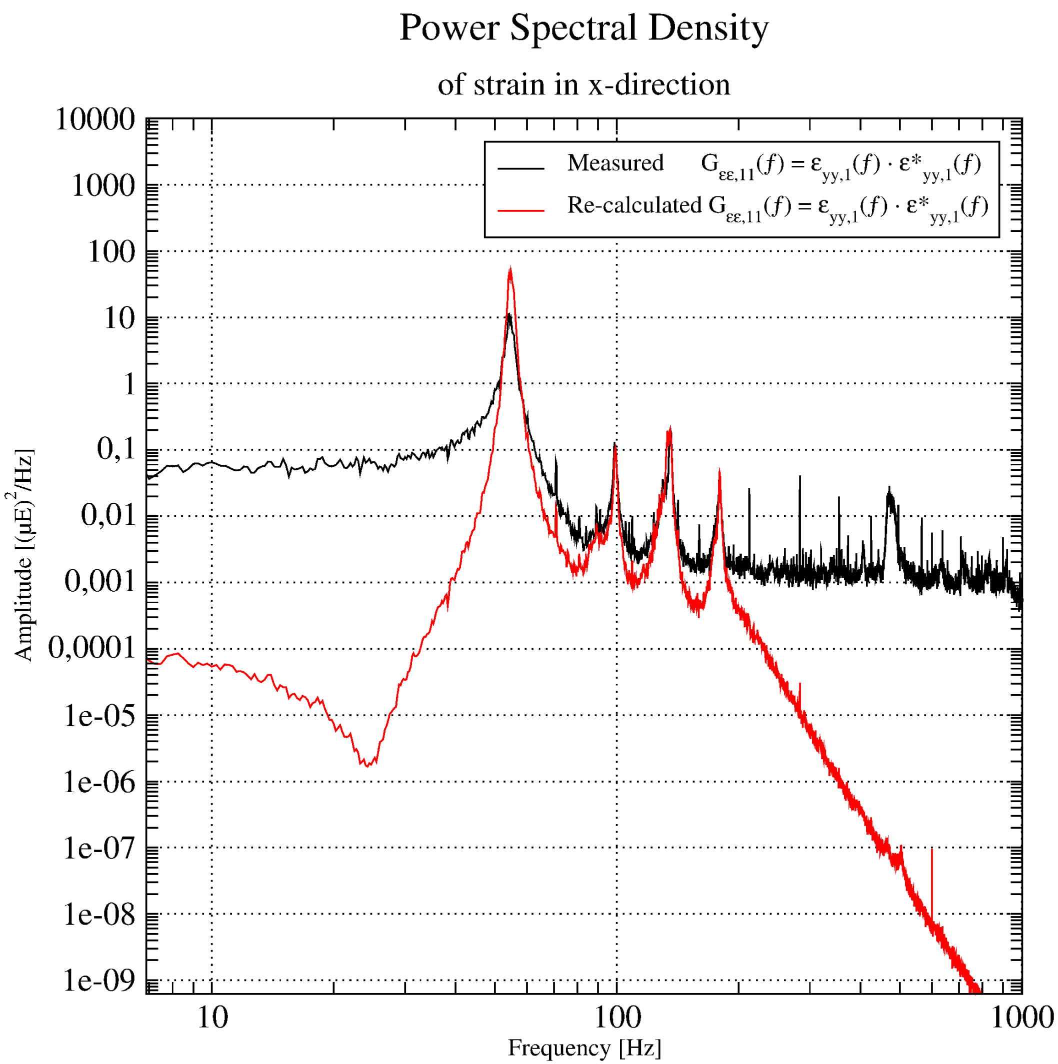
$$m_{air,i} = \square A \int \square^2_{air,i}$$

$$\square_{water,i} = \square \frac{\square^2_{air,i}}{\square^2_{water,i}}$$

$$\square_{water,i} = \frac{\square_{water,i}}{\square_{air,i}} \, \square_{air,i}$$

For each mode $i = 1, 2, 3, \ldots, n$

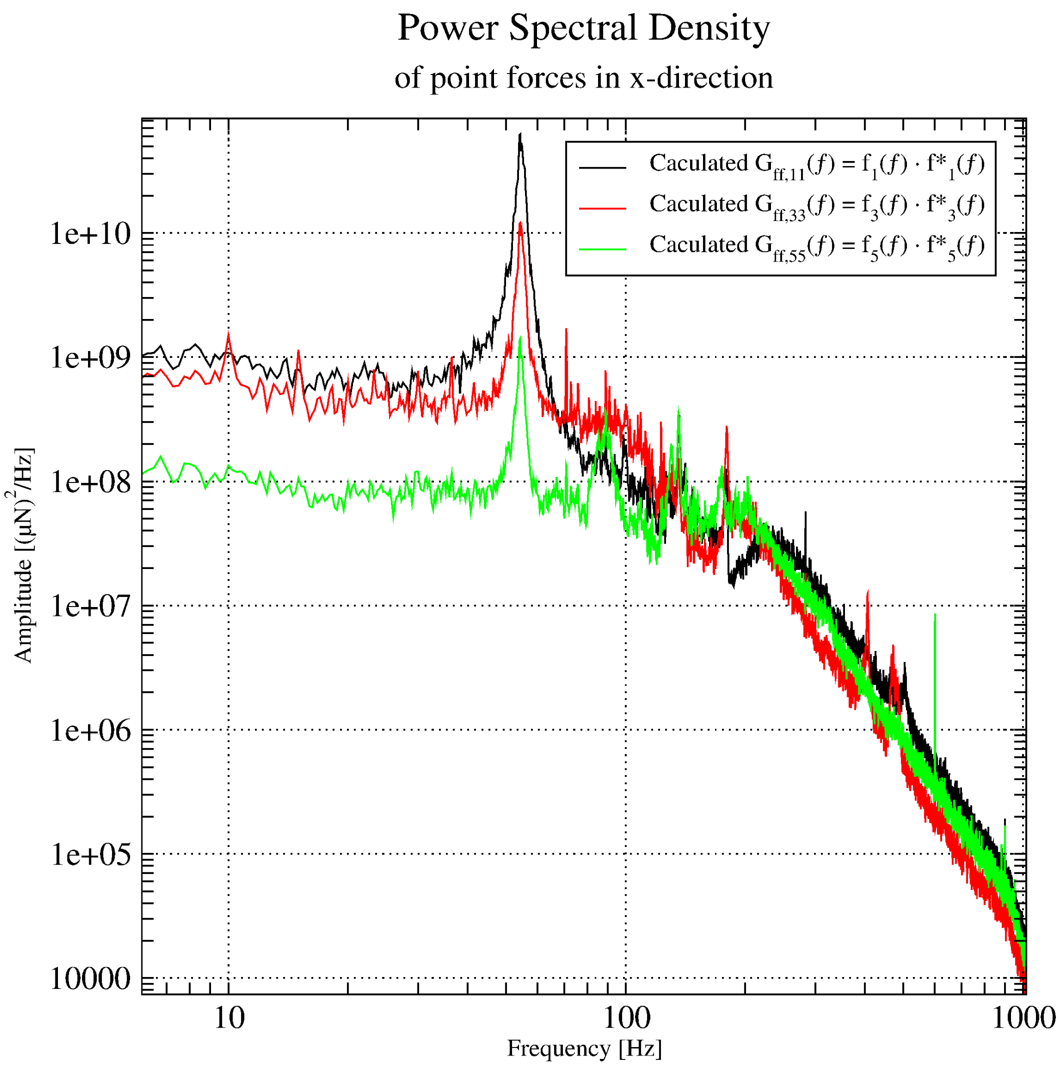
Results Method II



Measured and Re-calculated

Modelling the system using the re-normalised Mode-shapes in Air

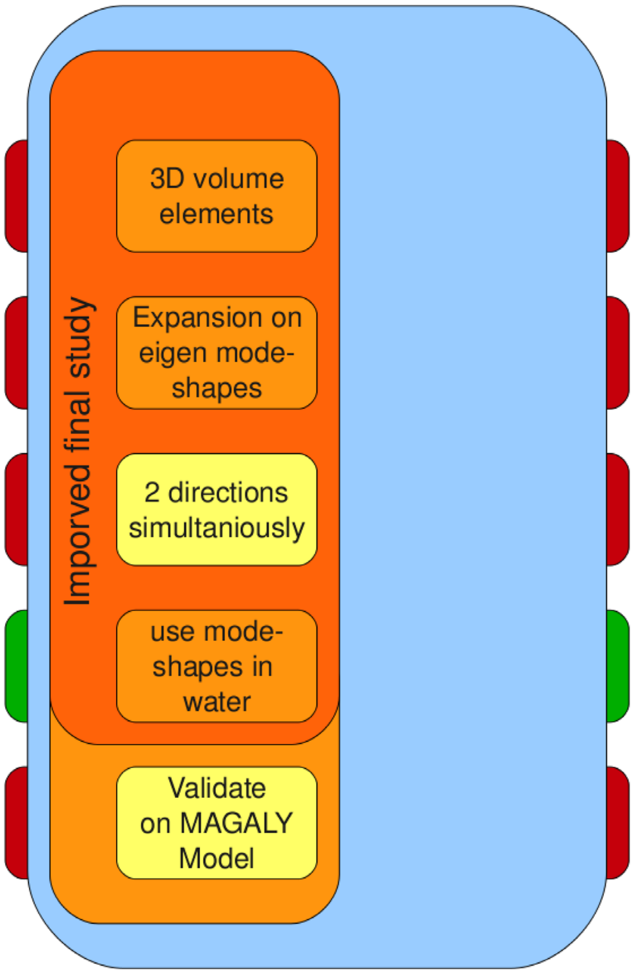
Results Method II



Calculated Point Forces

Modelling the system using the re-normalised Mode-shapes in Air

Conclusions



Use Mass Normalised Mode-shapes in water to describe the System

Questions

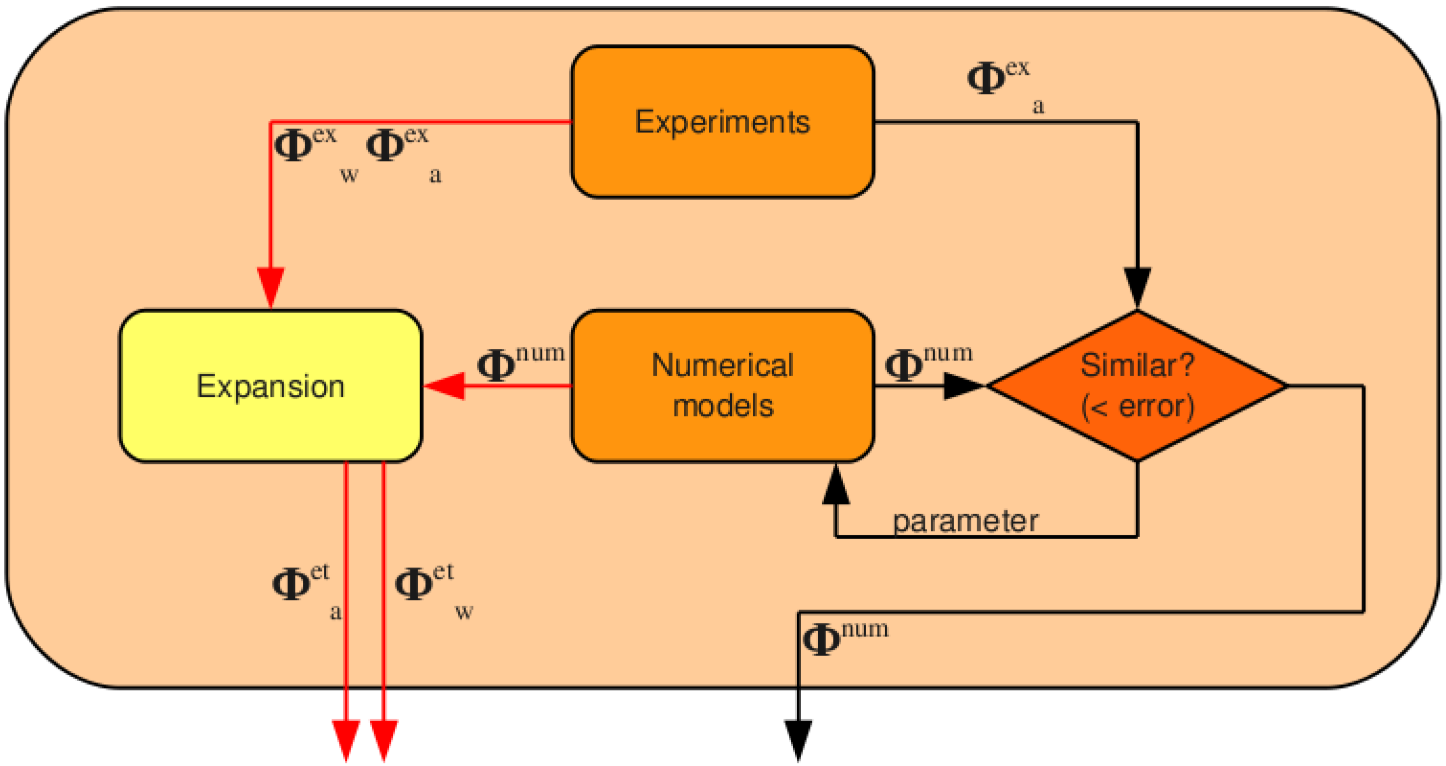
?

Conclusions

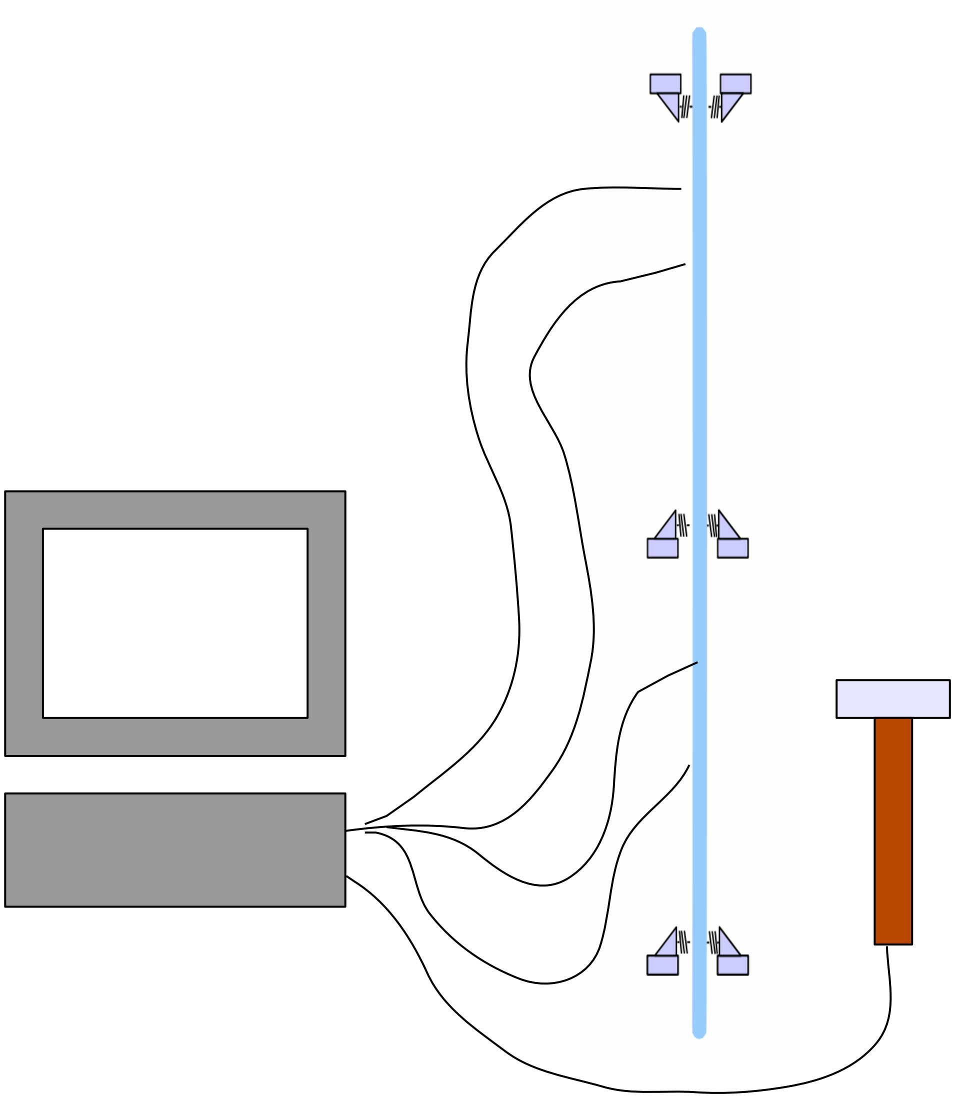
Experimental Mode-shapes obtained in Air are not Mass Normalised by the Measurement System

Transfering Identified Point Forces between different Models will not give the desired Result

Fundamental Problem with the Method: The measurment system uses a randomized signal if no input signal is measured.


Experiments
Φ^{ex}_{a}
Φ^{ex}_{w} Φ^{ex}_{a}
Expansion
Φ^{num}
Numerical models
Φ^{num}
Similar? (< error)
parameter
Φ^{et}_{a}
Φ^{et}_{w}
Φ^{num}

Experimental Modal Analysis



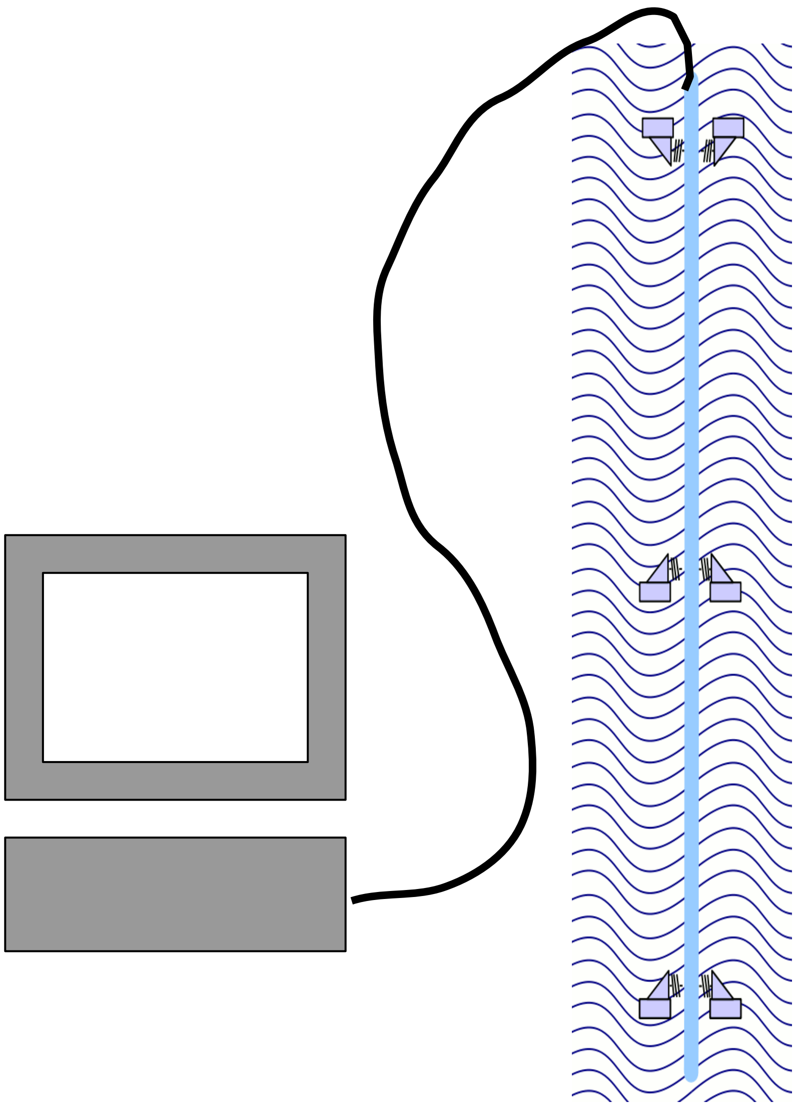
Hammer excitation

Measure the input and output signal

Mass Normalize the Mode-shapes

Extra

Operational Modal Analysis



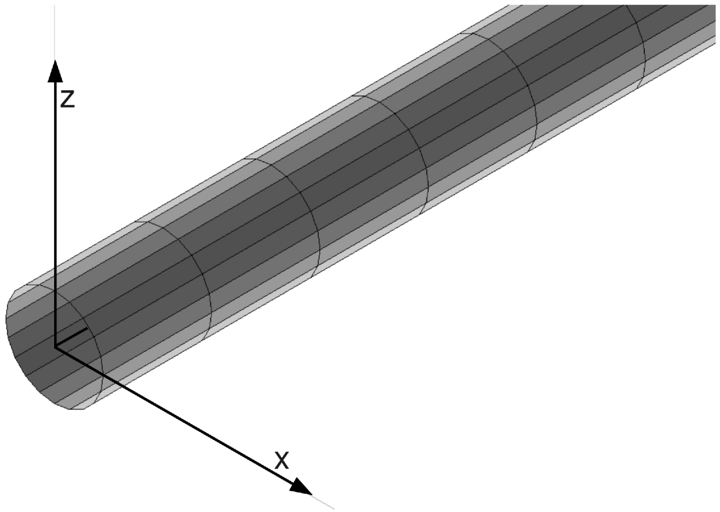
Strain gauges inside the tube

Measure only the output signal

No Normalized Mode-shapes

Extra

The Numerical Models



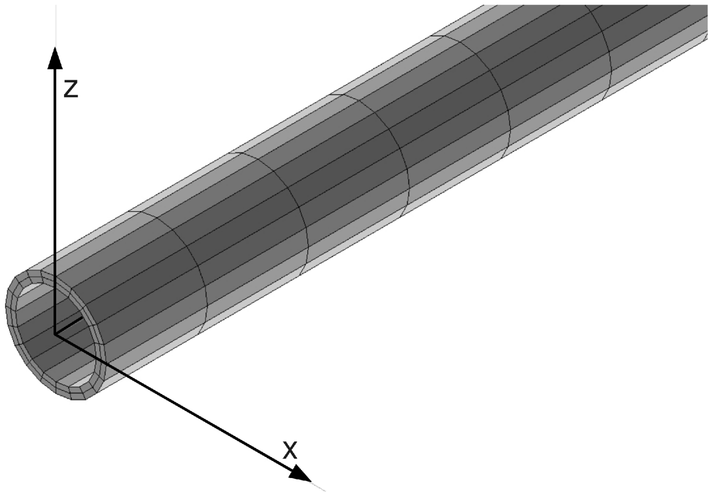
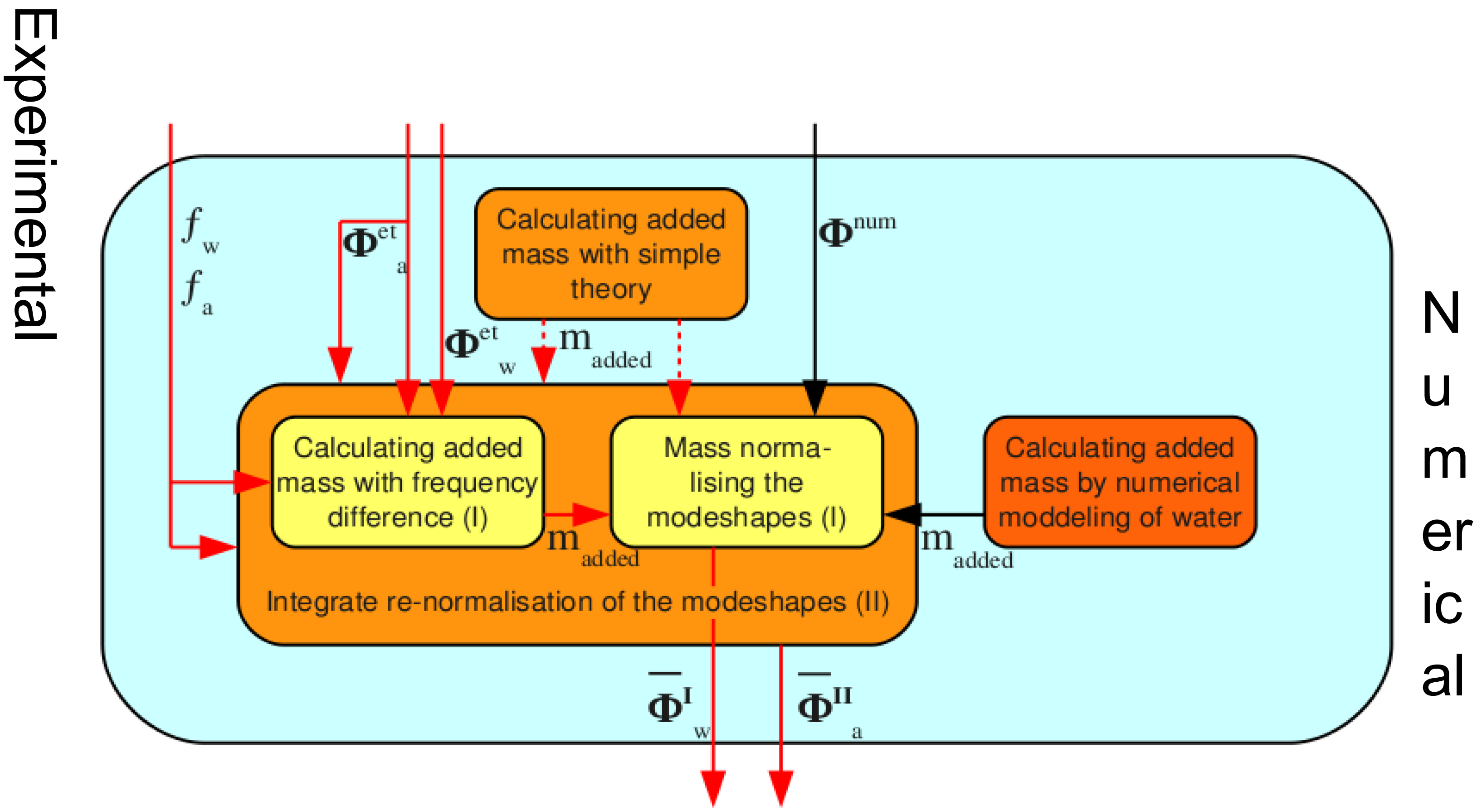


Table 4.15: Cross MAC of LMS experimental mode-shapes in water, expanded on mode-shapes of 3D model vs PAK experimental mode-shapes in air, expanded on mode-shapes of 3D model in displacement

vs.			PAK experiments in air, expanded on 3D model							
		nr.	1	2	3	4	5	6	7	8
	nr.	[freq.]	[70.26]	[70.26]	[111.89]	[111.89]	[154.69]	[154.69]	[202.61]	[202.61]
LMS experiments in water, expanded on 3D	1	[54.40]	0.780	0.202	0.002	0.004	0.006	0.001	0.010	0.005
	2	[55.37]	0.226	0.695	0.001	0.023	0.002	0.008	0.002	0.041
	3	[99.03]	0.009	0.012	0.929	0.023	0.002	0.020	0.000	0.002
	4	[130.35]	0.022	0.229	0.011	0.080	0.181	0.397	0.008	0.064
	5	[135.83]	0.021	0.113	0.001	0.012	0.755	0.075	0.000	0.000
	6	[179.22]	0.002	0.041	0.049	0.008	0.044	0.013	0.780	0.047

The Study



Experimental
f_w
f_a
Φ^{et}_a
Calculating added mass with simple theory
Φ^{num}
Φ^{et}_w
m_{added}
Calculating added mass with frequency difference (I)
Mass norma-lising the modeshapes (I)
Calculating added mass by numerical modeling of water
m_{added}
m_{added}
Integrate re-normalisation of the modeshapes (II)
$\overline{\Phi}^{I}_w$
$\overline{\Phi}^{II}_a$
Numerical

Assumptions

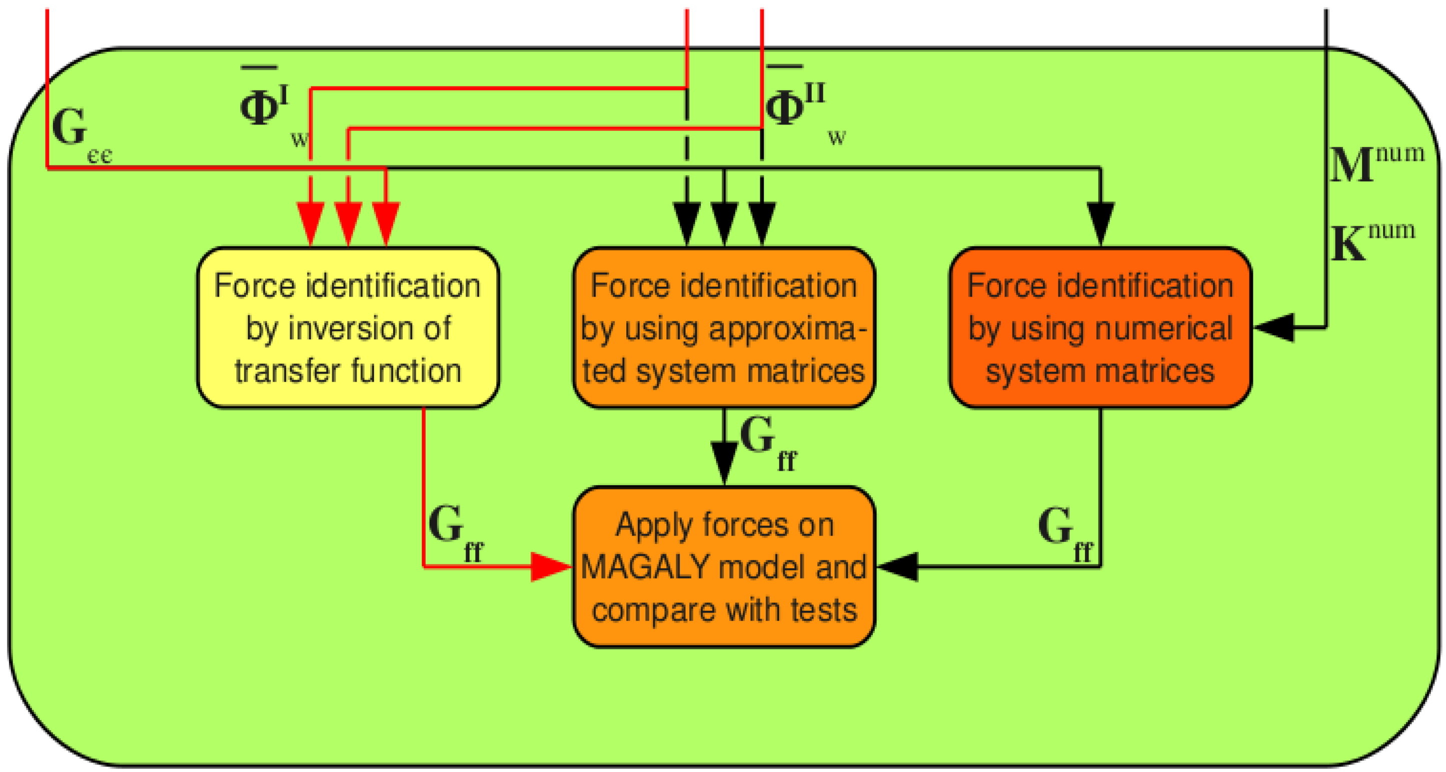
The mode-shapes are the same for the system in water and in air

(The Amplitudes of the modeshapes are not the same)

There is no added stiffness due to the water surrounding the tube.

The added mass due to the water surrounding the tube can be calculated from the frequency difference.

Experimental



Numerical