PIANC Workshop
13-14th September 2011

Part 5 – *Mooring forces and vessel behavior*

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"What's new in the design of navigation locks"

Workshop Part 5

Experience in France

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Introduction

Lock F-E system hydraulic design

F-E times
- System efficiency
- Easily accessible (1D, physical model)

"Hawser forces"
- System safety
- Which model should be used (1D, 2D, 3D, physical model) and when (conceptual design, final design)?
- Which component is calculated or measured (hydrostatic force, hydrodynamic force, reaction force in the mooring line) and how can you connect it to an acceptable value?

seems it raises some question…

…that will hopefully be answered by WG 155!!

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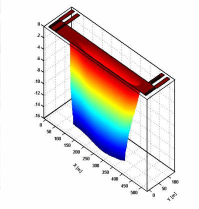
Available tools

➢ **1D numerical model**:
- assessment of the longitudinal water slope in the lock chamber and of the longitudinal hydrostatic force exerted on the vessel (F~ P x i)
- Fast track
- Results reliability (no consideration of dynamic effects)

➢ **2D numerical model (SWE)**:
- Calculation of the pressure field around the ship's hull
- Assessment of longitudinal a transversal water slopes in the lock chamber and of the longitudinal hydrostatic force exerted on the vessel (F~ P x i).
- Requires discharge time series



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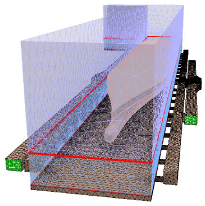
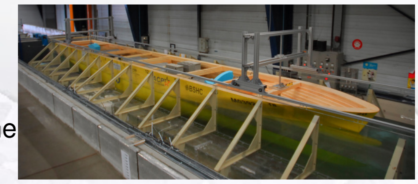
Available tools



- **3D numerical model**:
  - Modeling of the complete F-E system, lock chamber, vessel,
  - Can take into account FSI,
  - Calculation of the hydrodynamic force exerted on the vessel,
  - Calculation of the reaction forces in the mooring lines and vessel displacement,
  - Can do everything??!! → Restriction due to computational time & cost

- **Physical model**:
  - Allows to measure the hydrodynamic force (exerted on the vessel) and the water slopes
  - Can sometime be used to measure the reaction force in the mooring lines (depending on the mooring system)



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Studies carried out in CNR laboratory

	Lock dimensions	Vessel type	Methodology applied
Cremona Lock (Pô River - Italy)	200 x 12 m	Barges & tug - 5 900 T Barges & tug - 3 300 T	- Measurement on the physical model of the longitudinal and transversal forces & longitudinal water slope - Assessment of the hydrostatic force (F = Pxi)
New locks on the Rhône River	48 x 5 m	Leisure craft	Measurement on the physical model of the longitudinal force & longitudinal water slope
New Locks of Panama Preliminary design	430 x 55 m	12 000 TEU Container ship	- 1D model --> Discharge time series - 2D model --> Longitudinal & transversal WS - 3D model --> Longitudinal hydrodynamic force - Physical model --> Longitudinal & transversal hydrodynamic forces combined with a mechanical model in order to calculate the reaction forces in the mooring lines
New Locks of Panama Final design	430 x 55 m	12 000 TEU Container ship 8 000 TEU Dry Bulker	- 1D model --> Longitudinal water slope - Physical model --> longitudinal & transversal hydrodynamic forces combined with a mechanical model in order to calculate the reaction forces in the mooring lines and the vessel displacement

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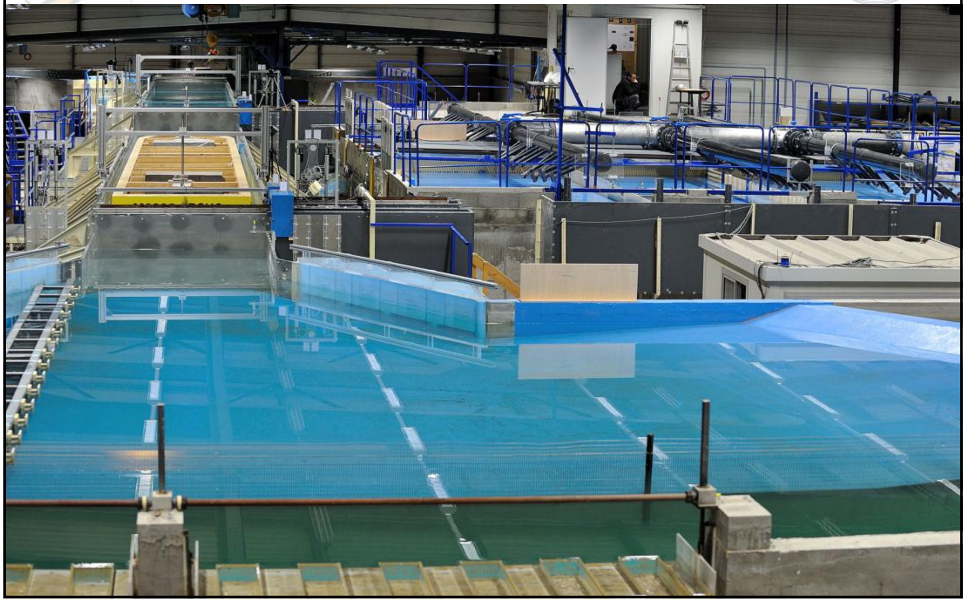
Panama Third Set of Lock – Final design study



"Hawser forces" measurement

Why not modeling of the mooring lines system on the physical model?

- It raises technical problem to represent faithfully the winches action on the lines and to manage the lines tension when the vessel is raising up or going down,
- It gives very unique tests conditions according to the number, positions, tension of the mooring lines that does not permit tests repeatability.

→ Decision was made to measure the forces exerted on the vessel and to use a numerical mechanical model of the mooring line system to determine reaction forces and vessel displacement

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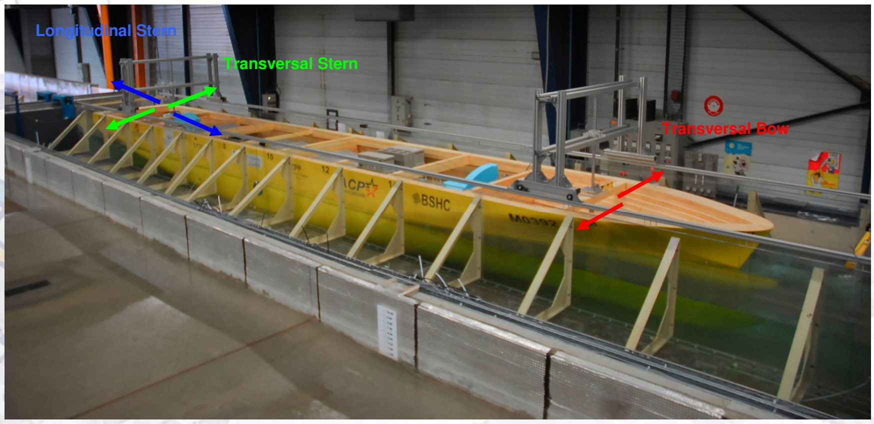
Measurements on the physical model

3 dynamometers:
- 1 longitudinal sensor (stern)
- 2 transversal sensors (1 stern, 1 bow)



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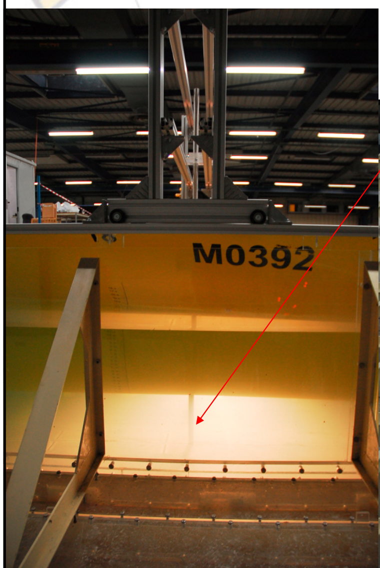
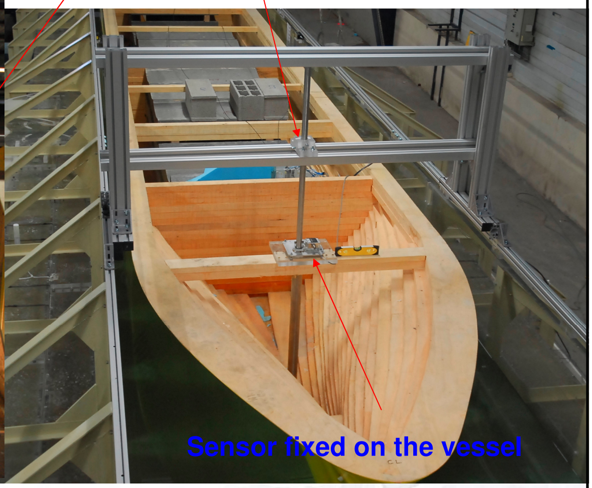
Measurements on the physical model

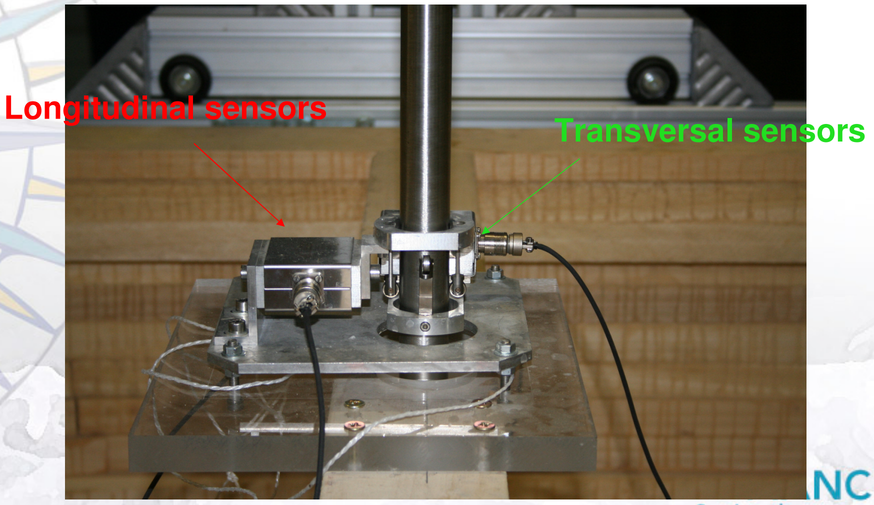


Vertical bar fixed to the bottom floor and above the vessel



Measurements on the physical model

Stern sensor details



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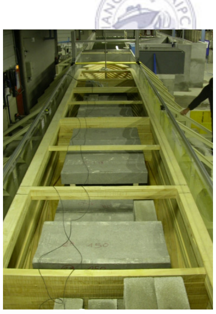
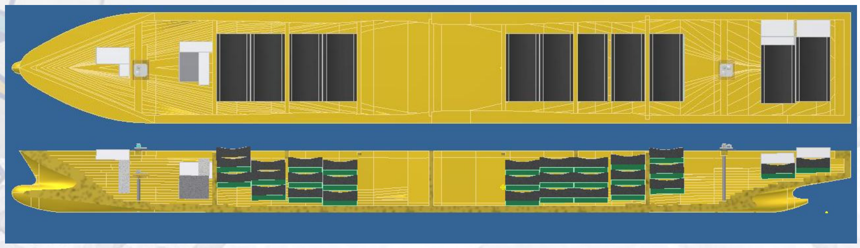
Measurements on the physical model

Definition of the loads position in order to reach the correct value of:

- the total mass,
- the position of the centre of gravity,
- the inertia momentum (Izz)





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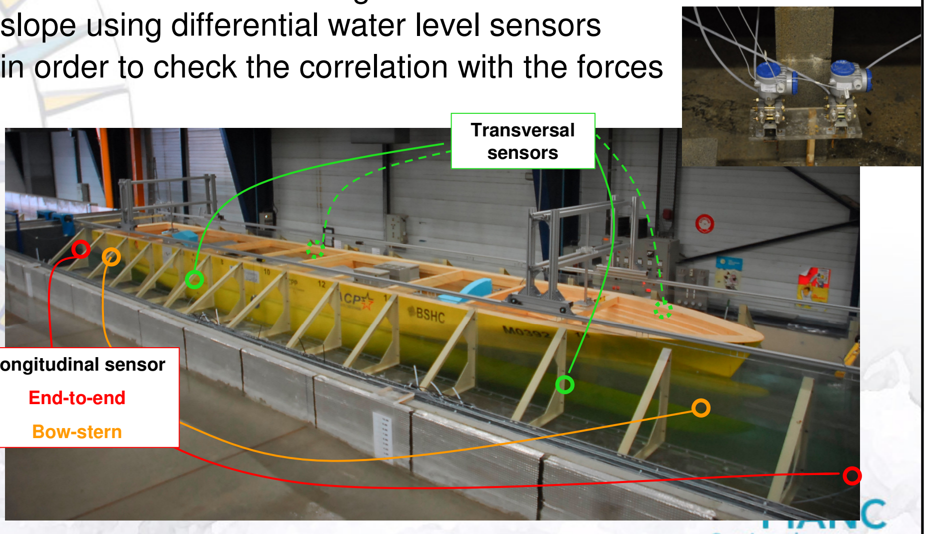
Measurements on the physical model

Measurements of the longitudinal and transversal water slope using differential water level sensors in order to check the correlation with the forces



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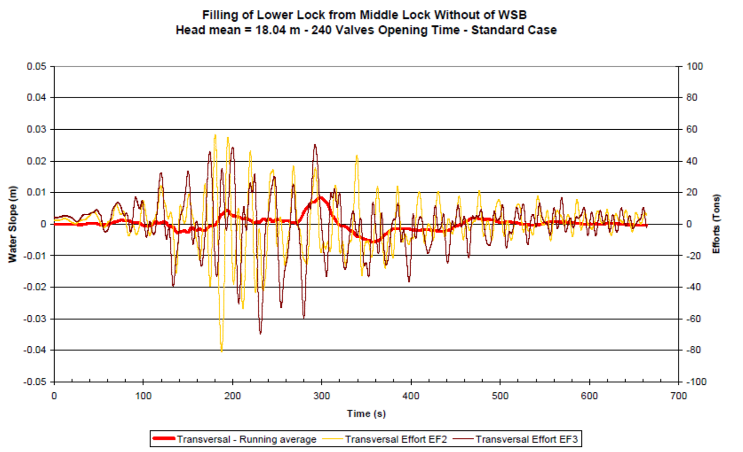
Measurements on the physical model

Characteristic results from a test:



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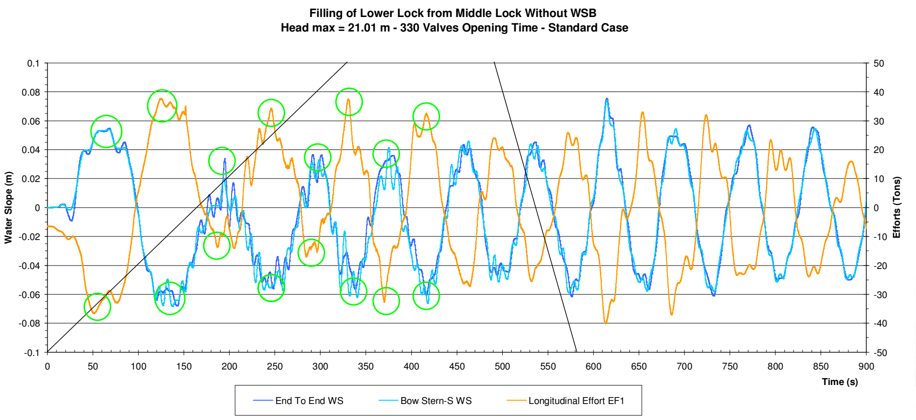
Prediction of the forces



Search for correlation between longitudinal water slope with the vessel in the lock chamber and the longitudinal hydrostatic forces exerted on the ship's hull

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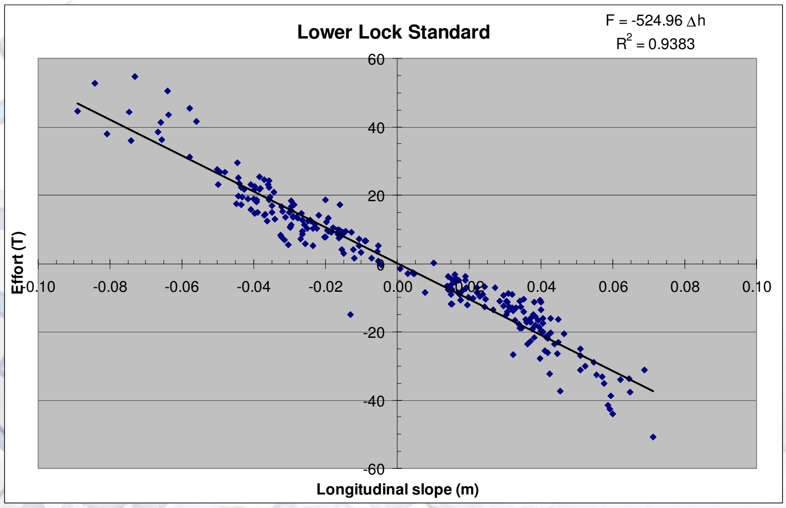
Prediction of the forces



→ Can be used to assess the weight of the hydrostatic force component in the total force

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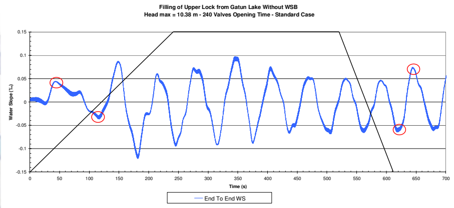
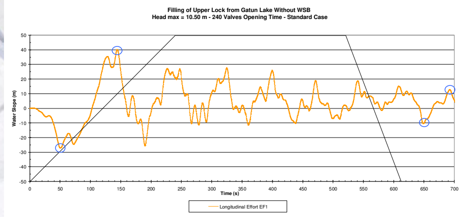
Prediction of the forces

For every hydraulic scenario, two tests have been performed, one with the vessel and one without

Search for correlation between longitudinal water slope without the vessel in the lock chamber and the longitudinal hydrostatic forces exerted on the ship's hull → Characterization of the F-E smoothness??



Measurement of the longitudinal water slope without the vessel in the lock chamber



Measurement of the longitudinal forces exerted on the vessel

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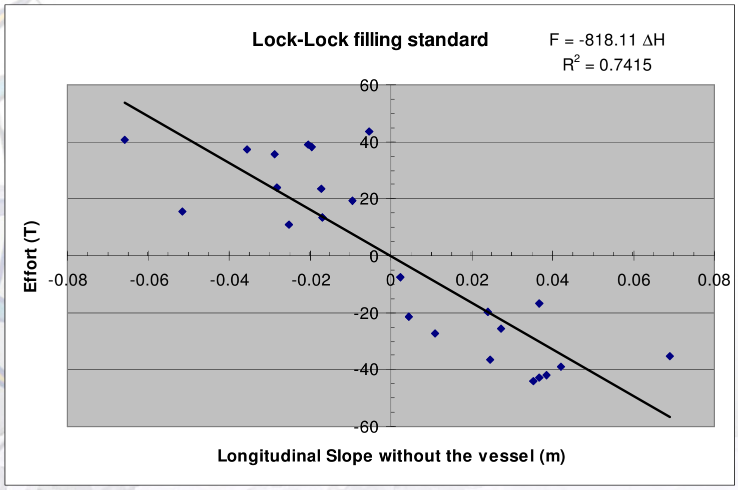
Prediction of the forces



→ As expected, the correlation is not so good but can still give valuable information

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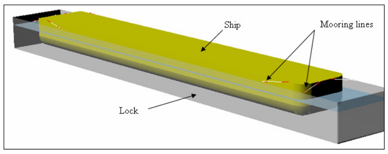
Numerical calculation of forces in the mooring lines

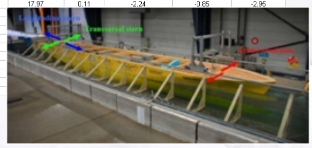
To study the ship dynamic behaviour and the mooring lines forces in post-Panamax lock, a numerical simulation model of the ship and its mooring lines has been built with MSC-Adams software[1] by SIREHNA



This numerical model is fed by measurements time series performed by CNR on the experimental model :

- *Water height in the lock chamber*
- *Longitudinal hydrodynamic forces exerted on the ship*
- *Transversal (bow and stern) hydrodynamic forces exerted on the ship*

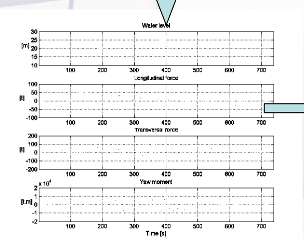
Lock-lock filling - Maximum initial head without WSB						
Water level in the lock chamber (Sampling frequency 10 Hz)			**Hydrodynamic forces (Sampling frequency 150 Hz)**			
Time	Water level in the lower chamber	Water level in the upper chamber	Time	Longitudinal effort EF1 (Stern)	Transversal effort EF2 (Stern)	Transversal effort EF4 (Bow)
time step (s)	0.1	0.1		0.0067	0.0067	0.0067
sampling nb.	2193	2193		32895	32895	32895
Average	5.3484	10.376		4.3671	-4.3187	-0.9351
TCL	Z5	Z8	TCR	EF1	EF2	EF4
s	mPLD	mPLD	s	T	T	T
0.00	-2.20	17.97	0.00	-2.21	-0.61	-3.13
0.55	-2.20	17.97	0.04	-2.19	-0.63	-3.04
1.10	-2.19	17.97	0.07	-2.18	-0.70	-3.03
1.64	-2.19	17.97	0.11	-2.24	-0.85	-2.95
2.19	-2.19					
2.74	-2.19					
3.29	-2.19					
3.83	-2.19					
4.38	-2.19					
4.93	-2.19					
5.48	-2.19					
6.02	-2.20					
6.57	-2.19					
7.12	-2.19					



[1] Used to study the 3D full-motion behavior (displacements, velocities, accelerations, forces) of complex mechanical systems

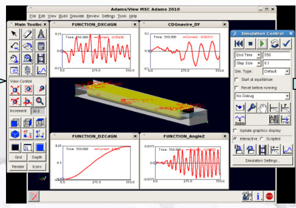
Process synopsis

Physical model operated by CNR

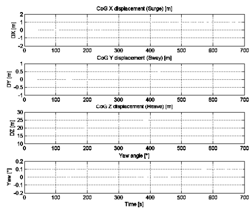


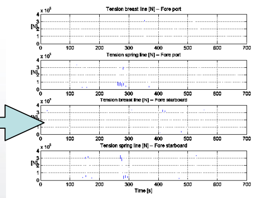
Water height and hydrodynamic forces

Longitudinal force, transversal forces at bow & stern



Numerical model operated by SIREHNA



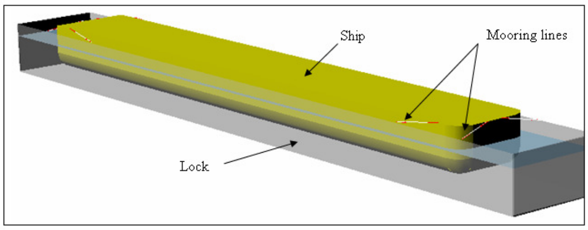


Ship displacements and forces in mooring lines

Numerical modelling

The numerical model (built at full scale) includes :
- The lock chamber,
- The vessel modelled as a rigid body
- The mooring lines attached to the ship and to fixed bollards on top of the lock wall

Contacts between ship and lock walls are automatically detected and are managed with simplified reactions models (no accurate enough for the modelling of fenders)



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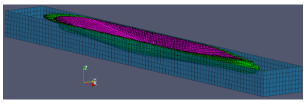
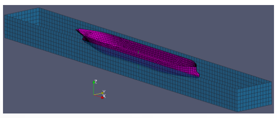
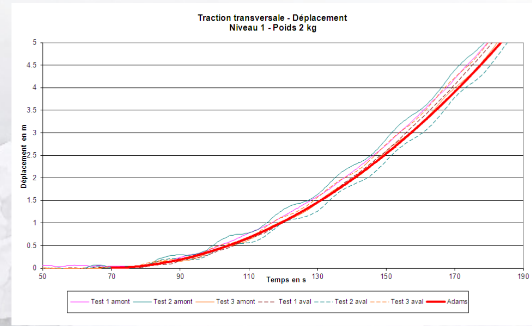
Ship modelling

Ship modelled as a rigid body
Defined by its geometry, inertial characteristics, its added masses and damping coefficients.



Added masses and damping coefficients (surge, sway and yaw) have been determined experimentally from model tests, by identification approach. Coefficients also assess with a potential flow code





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Ship modelling

➢ ***Hydrodynamic forces***

Surge, sway and yaw forces result from measurements carried out on t physical model. These hydrodynamic forces, functions of time, are applied at the ship's centre of gravity

➢ ***Ship Motions***

Ship lift and descent taken into account : heave motion results from the measurements and imposed at the ship's centre of gravity

Roll and pitch motions are not taken into account (set to zero)

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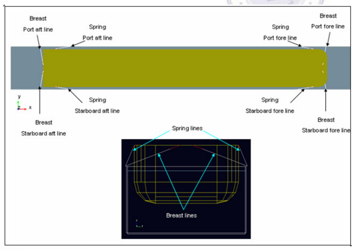
Mooring lines modelling

➢ **Mooring system lines configuration & location**

4 breast lines + 4 spring lines



➢ **Mooring lines characteristics**

Samson Proton-8 strand lines (∅ 57 mm)
Min. Breaking Strength (MBS): 174t
Linear elongation assumed: 0.87% at 20% of the MBS

➢ **Definition of mooring lines operating mode**

Mooring line modeled by an effort function of the distance between the 2 ends. It behaves like a spring with linear stiffness : $T(t) = k\ (L(t) - Lo)$ with k : stiffness; L (t) : distance between 2 ends; L_0 distance relative to initial tension

Operating mode

- *Selection of an initial pre-tension T0 for each line: 0.2 x MBS*
- *Selection of the maximum allowable tension in a line (when lines tension rises over this value, the mooring line is released)*
- *The mooring lines can be completely slack (tension equal to 0)*

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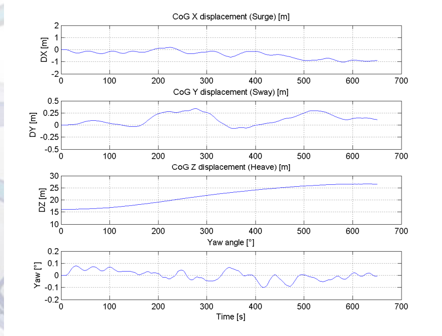
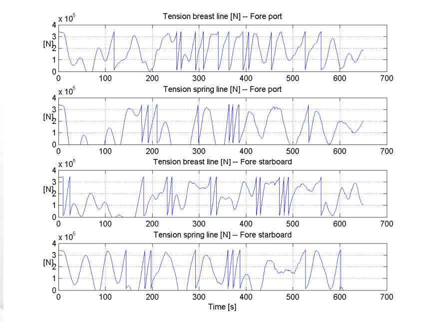
Results achieved

Vessel displacements, tensions in mooring lines and detection of collisions with lock walls or lock gates





Modal analyses of the different mechanical models done in order to assess the risk of resonance (comparison of the mooring line system natural periods with the hydrodynamic force periods)

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Conclusions

- A numerical model of a ship and mooring lines system, fed by measurements made on a physical model has been developed
- This methodology gives access to the forces exerted in the mooring lines and to the vessel displacements
- This methodology is very flexible. It allows to investigate a large number of configurations and situations in short time allowing to compare different mooring lines systems for one given hydraulic scenario
- Measurements are done with a ship fixed and centered in the lock, therefore the main hypothesis concerning the hydrodynamic input forces, is that during the simulation (F-E operations) the ship remain sufficiently close to its initial position. The results show, that in the majority of the cases studied, the displacements remain at low level.

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Thank you

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Fabian Pecot — Sirehna, France

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