Numerical simulation and experimental models:
How to choose?

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Hydraulics design for navigation locks

- In the chamber
  - ✓ Filling-emptying system
  - ✓ Flow in chamber and culverts
  - ✓ Water surface slope and forces acting on the ships (mooring design)
  - ✓ Turbidity current, salinity
- For the mechanical equipments
  - ✓ Valves design, head losses determination, air-entraining, vortices, cavitation
  - ✓ Gates sollicitations, operations
  - ✓ Flow induced forces and vibrations
- Upstream and dowstream the lock
  - ✓ Near field: currents, eddies in the inlet
    design of the navigation approach-harbours to the lock
  - ✓ Far field: dowstream and upstream lockage waves
    bank protection
    interaction navigation-bank,
- Eco-hydraulic
  - ✓ Fish migration
  - ✓ Hydropower and green energy

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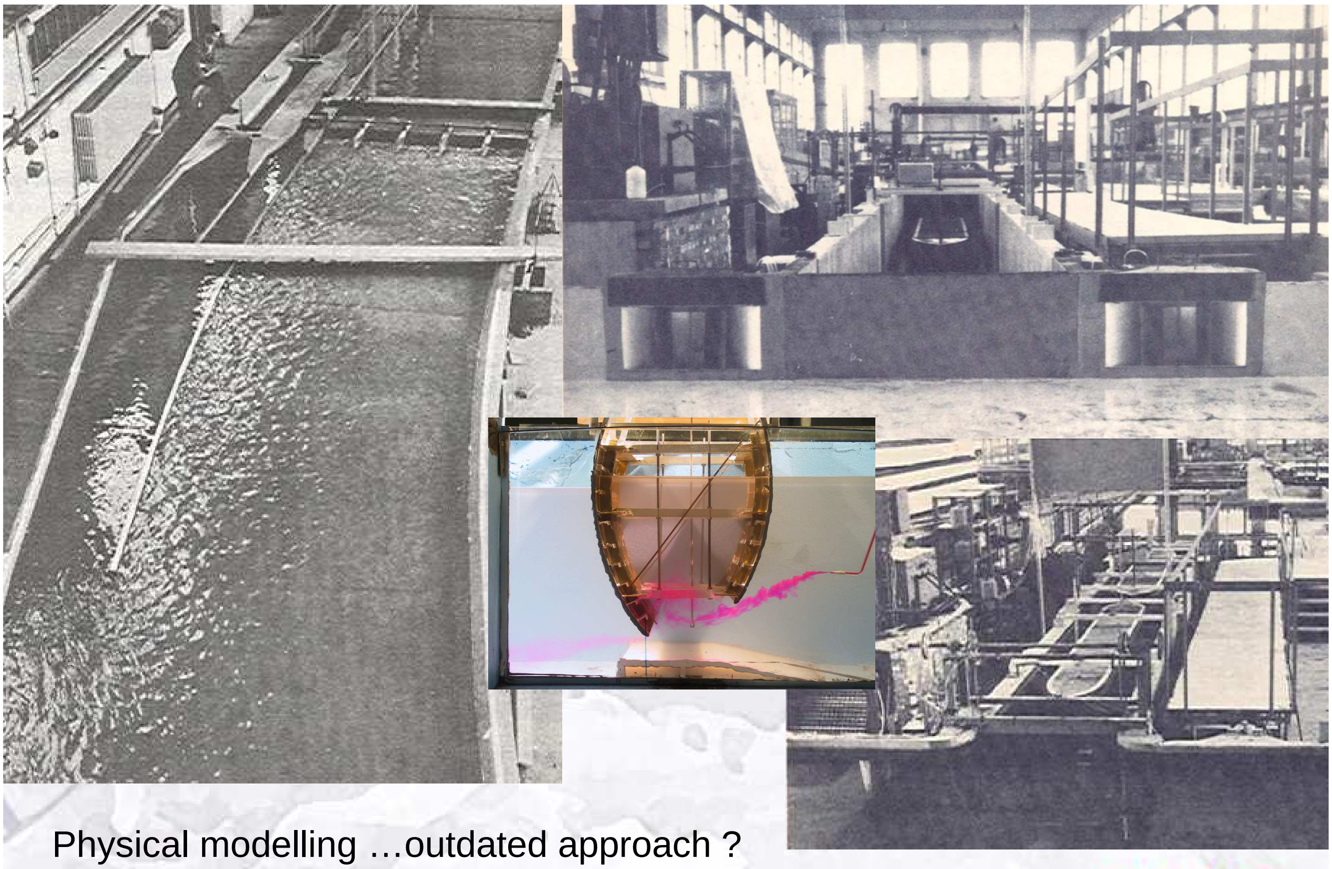
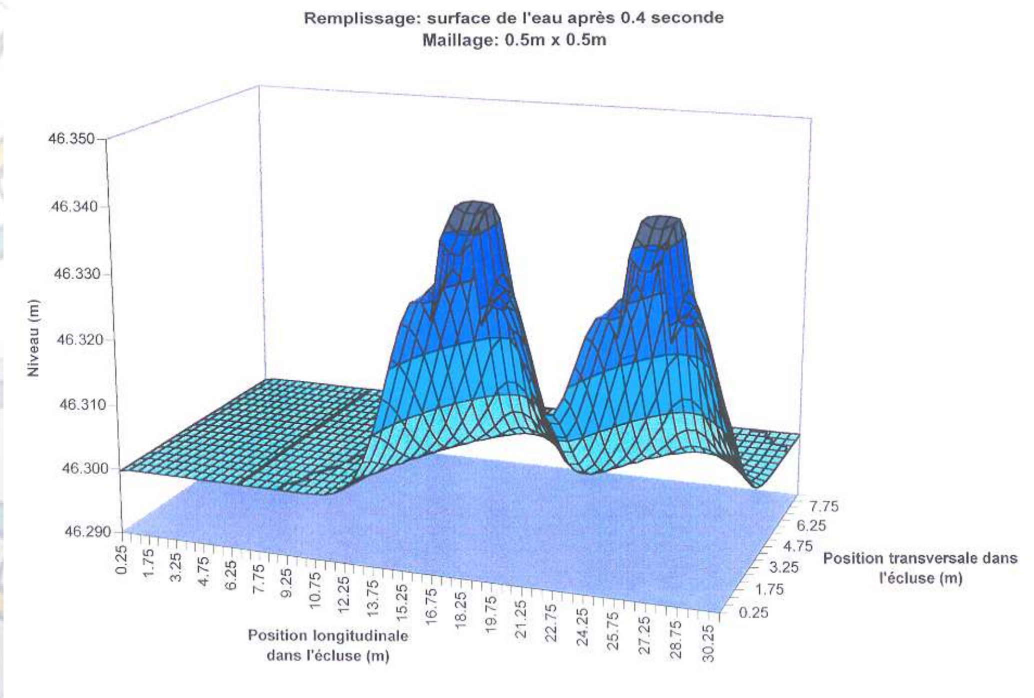
Hydraulic tools

- Analytical model — exact mathematical solution for simplified equations
- Numerical model — approximative solution, domain and boundaries conditions
- Physical model — reduced scale model, approximative solution
- Test model — simple conceptual physical model (no scale)
- Field measurements

Introduced the concept of Composite modelling



Physical modelling …outdated approach ?



Numerical modelling… absolutely confidence ?

Thus…

- Why to maintain costly facilities test hall !
- But, how to improve an efficient mean of communication to present the real-world situation?

Acknowledgements

- The market shares of the numerical models have increased in the last century against the physical models.
- Less experimental activities have been noticed.
- Nevertheless, physical models are *in fine* guarantying the precision of the design results.
- Physical models vs. numerical models: strengths and weakenesses.

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Conceptual comparison between hydraulic and numerical models to engineering problems

Step	Hydraulic model	Numerical model
1	Definition of	the problem
	Identification of the	essential acting forces
2	Formulation of similarity requirements	Formulation of a set of equations
3	Formulation of	boundary conditions
4	Construction of a model	Development of a numerical scheme
5	Calibration and	validation
6	Measurements converge to solution	Calculations converge to solution

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Limiting factors

- **Concerning the physical modelling :**

1st limiting factor	-compromise to choice the similarity
2d limiting factor	-influence of the sufarce tension
3th limiting factor	-effect of the distorsion
4th limiting factor	-effect of the sedimentology time and turbulence generated by bottom morphology

- **Concerning the numerical modelling :**

1st limiting factor	-complexity of the equations -sediment transport processes -turbulence effect
2d limiting factor	- numerical models are global and physical models are local
4th limiting factor	-interferences introduced by the simplifications of equations -interferences introduced by the algoritmic developments
4th limiting factor	-calibration and validation difficulties

Principal and practical limiting factors

HYDRAULIC MODEL	NUMERICAL MODEL
Principal	**limitations**
Model size (laboratory)	Storage capacity
Discharge (pumping capacity)	Computational speed
Energy head (pumping capacity)	Incomplete set of equations
Model laws	Turbulence hypothesis
Practical	**limitations**
Minimum model scale (surface tension, viscosity, roughness,…)	In simplified set of equations: -accuracy of assumed relationships -availability of coefficients
Model size (upper limitation)	Space and time resolution
Measuring methods and data collection	Numerical stability and convergence
Availability of boundary and initial conditions	Availability of boundary and initial conditions

Hydraulic or numerical model
Decision criteria

- Principal limiting factors
- Required accuracy
- Simplicity
- Cost and time requirements
- Flexibility
- Intuitive power
- Credibility
- Feedback to nature (calibration possibilities)
- Prognostic capabilities

Type of model	Hydraulic model	Numerical model
River and tidal models with fixed bed	Local problems, complex geometry	Large scale problems, simple geometry
River and tidals models with movable bed	Bedload transport, erosion ans deposition problems	Suspended load transport (bed load transport for very simple geometry)
River and tidal models for transport processes	Near-field problems	Far-field problems
Lake and reservoir models	Detailed questions, fundamental experiments	Mainly used
Harbour and coastal models	Mainly used	Wave pattern for simple geometry
Models of hydraulic structures:		
-Discharge characteristics	Complex geometry	Simple geometry
-Energy dissipation	Complex geometry	Simple geometry
-Erosion	Necessary	Simple geometry
-Flow forces	Complex geometry	
-Vibrations	Neccessary	
-Cavitation	Necessary	
Pipe flow models	Local problems, complex geometry, sediment	Mainly used

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1. The contribution of analytical, numerical and experimental modelling

A comparison of experimental and numerical models shows at first glance that both type of model have very much in common. Each must be preceded by a conceptual phase, in which the physical relationships are identified which are to be simulated by the model.

2. Comparison between each models, limitations

The effort in constructing a hydraulic physical model is comparable to the effort of working out a solution scheme for the numerical model. Both methods must make use of certain simplifications and approximations and have to be adapted to the real situation in nature – in the one case by adapting the empirical coefficients, in the other case by changing the model roughness.

3. Decision making process

The most important role in the decision making process is played undoubtedly by the limiting factors of either of model and the negative effects in modelling.

Because these two types of model lead to approximate solutions, when using them one has to know how approximate the solution is, that is, it's precision. One way to know is to use all three types of models, and to combine them so as to avoid their main shortcomings.

4. Contribution for pluridisciplinary expertise and public relation

Physical model is an efficient mean of communication that allows to present the real-world simulation, helps learning about the processes involved and convince of the relevance of works wich improve multidisciplinary approach.

Hydraulic studies

METHODOLOGY

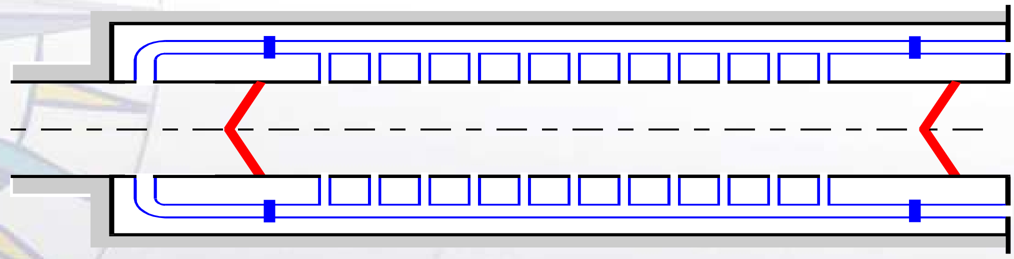
Physical modelling | Field measurement | Numerical modelling

Composite modelling to optimize the methodology and reduce the parasite effects generated by physically and numerically approach

1st Example
Lanaye 4
Filling-emptying system for a lock

Filling and emptying systems

Longitudinal culverts with branch culverts



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Numerical model elements

- **Culverts, branches and valves**
  - Pressure pipes
- **Lock chamber**
  - Open-channel flow (SWE), 1D and 2D
- **Coupled modelling**
- **Boundary conditions**
  - Upstream and downstream water levels

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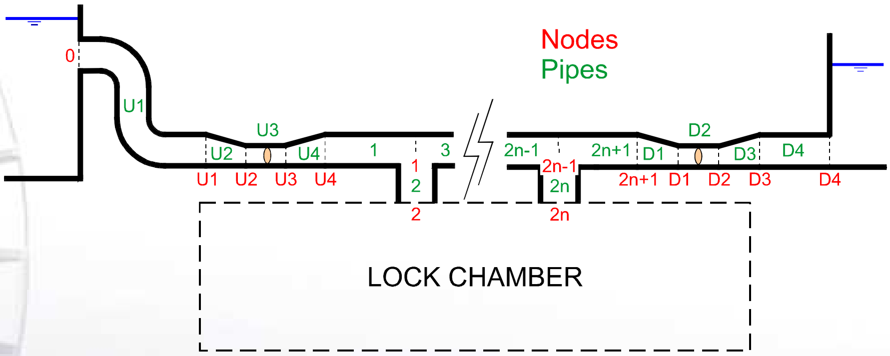
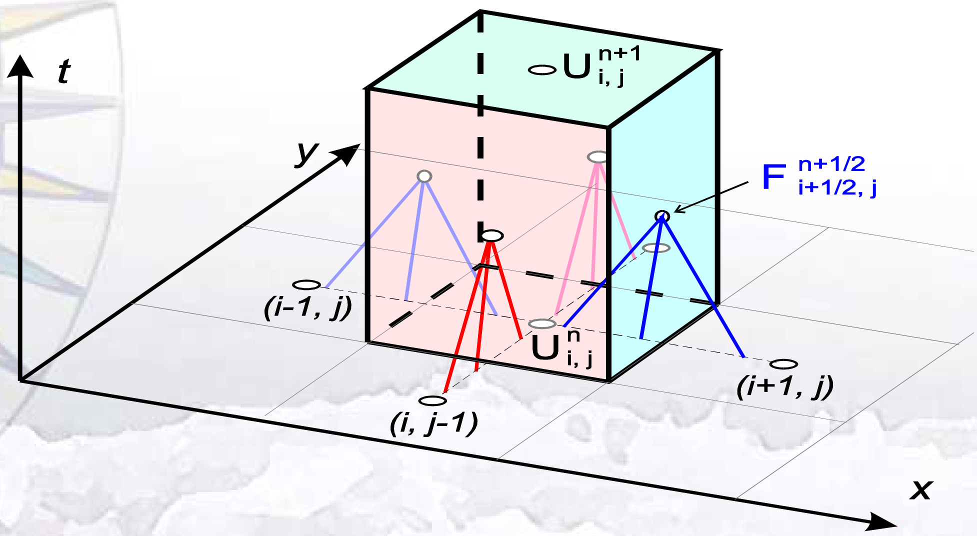
Pipes modelling

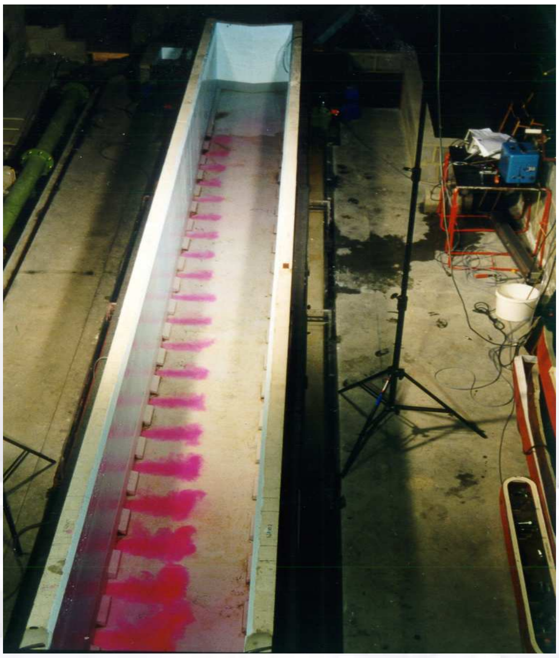


- Elements: pipes and nodes
  - Unknown: head H, velocity V
  - Mass continuity at nodes
  - Energy equation on pipes
  - BC: Upstream, downstream and chamber water levels

SWE integration
Finite volume scheme



Filling visualisation (Scale model)



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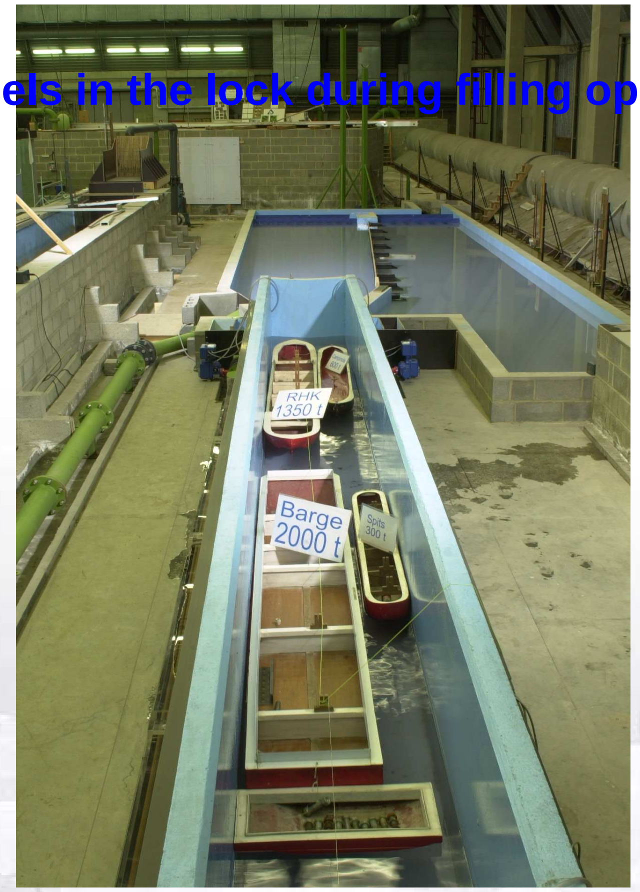
Vessels in the lock during filling operation



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Lanaye IV study

- Comparison with scale model
  - Adapted valve diameter
- Comparison with Lanaye III Lock
  - On-site measurements
  - Adapted culvert layout
  - Numerical model validation
- Lock 225 m x 25 m
  - 2D model of chamber : optimisation

2d Example
Ivoz-Ramet complex
Upstream and dowstream harbours

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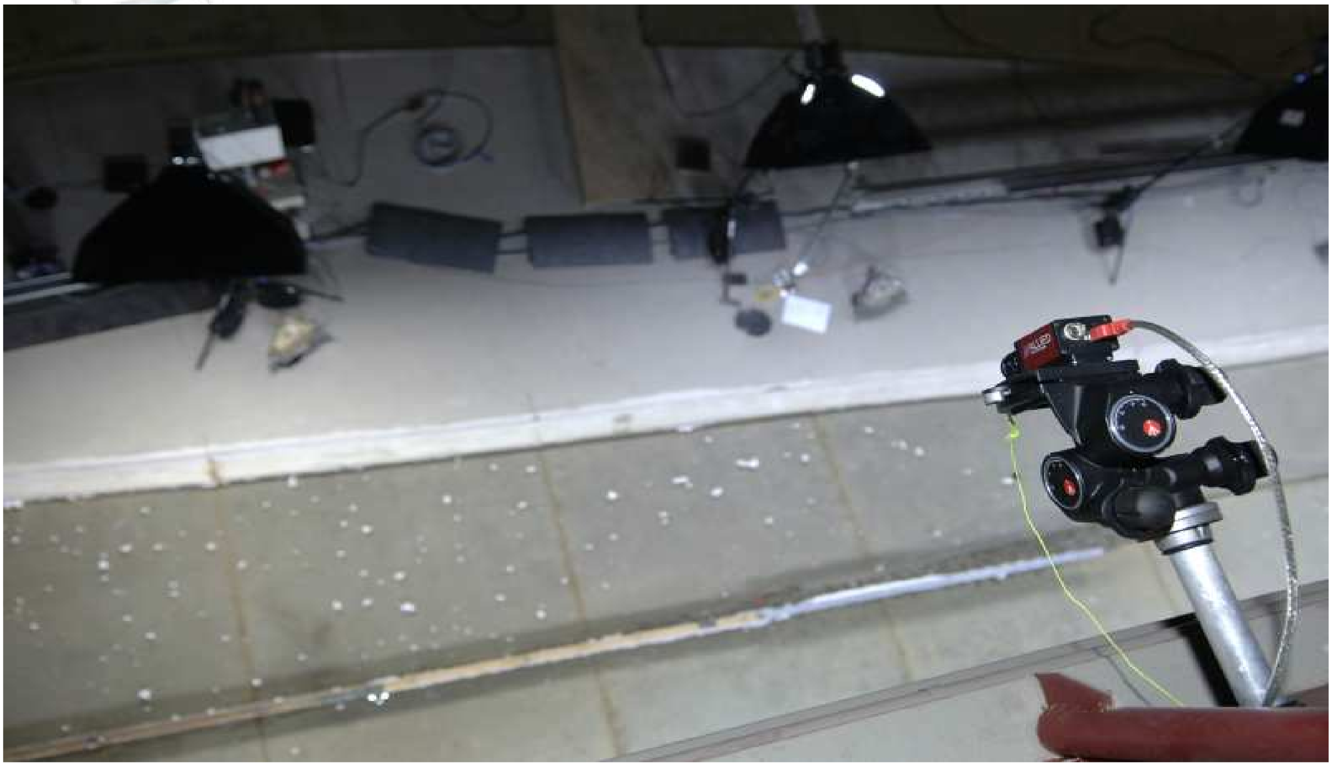
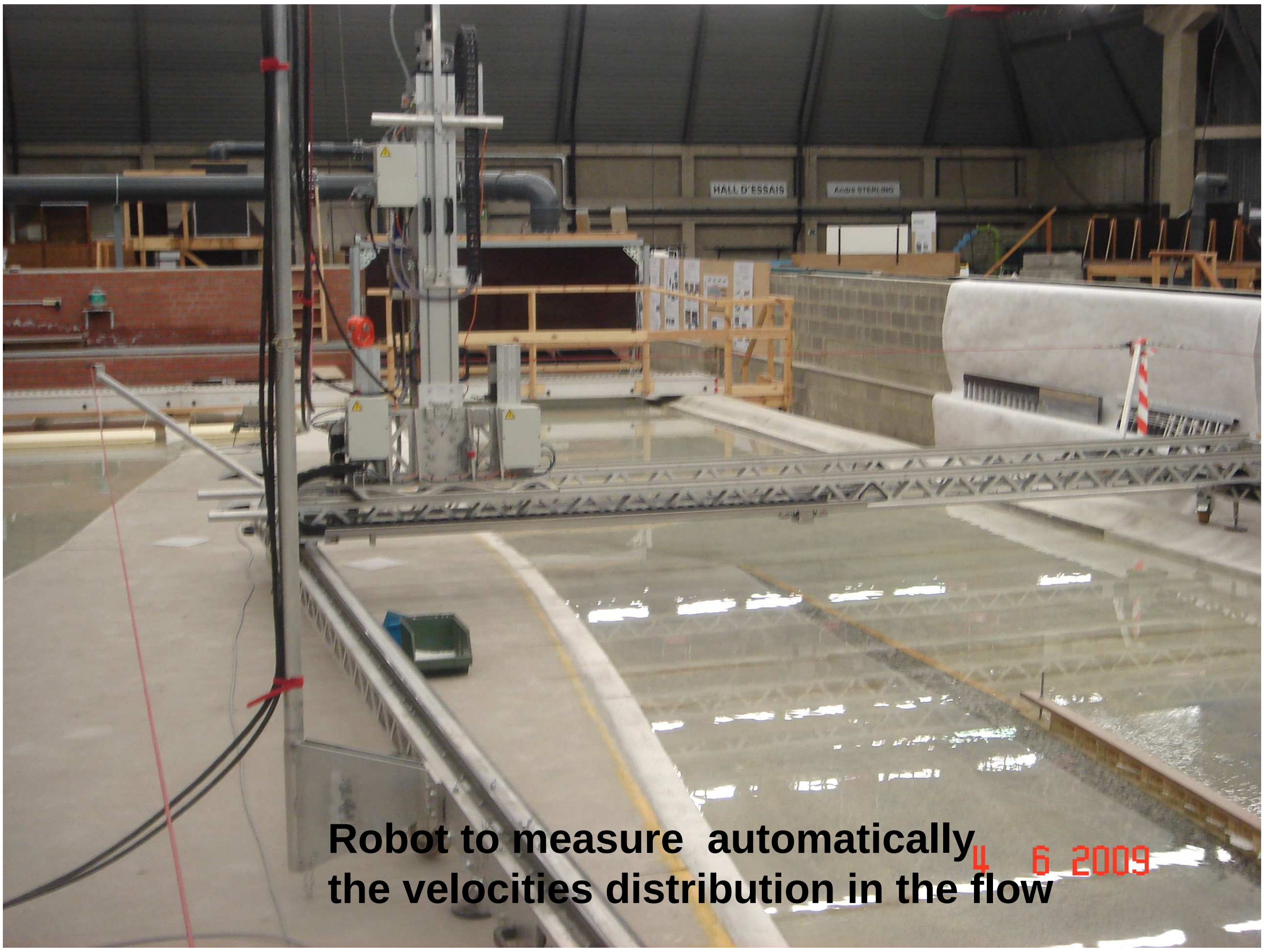
Methodology

- Stream evaluation
  - Physical model 1/50
  - Numerical model TELEMAC 2D
- Navigation simulation
  - Numerical simulator (ALKYON)
- Impacts on the river
  - Waterprofiles – 1D modelling
  - Waves generated by the lock operations – 1D unsteady numerical model

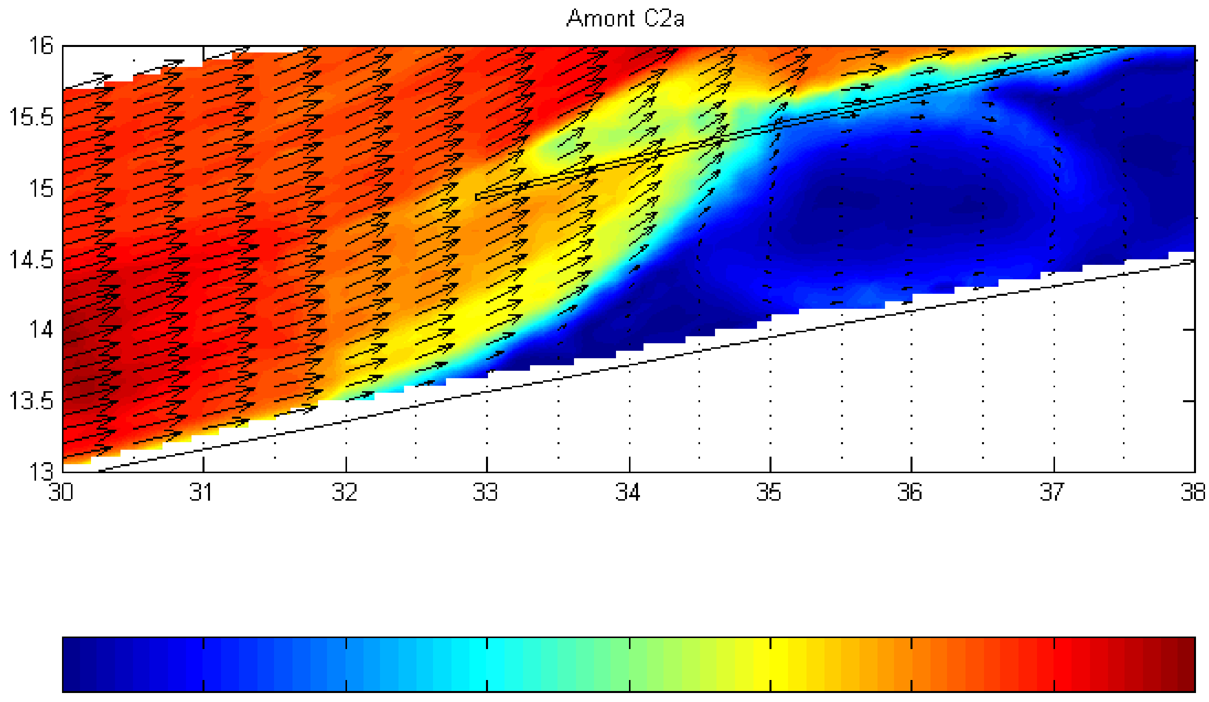
Physical model

Video streamlines measurements



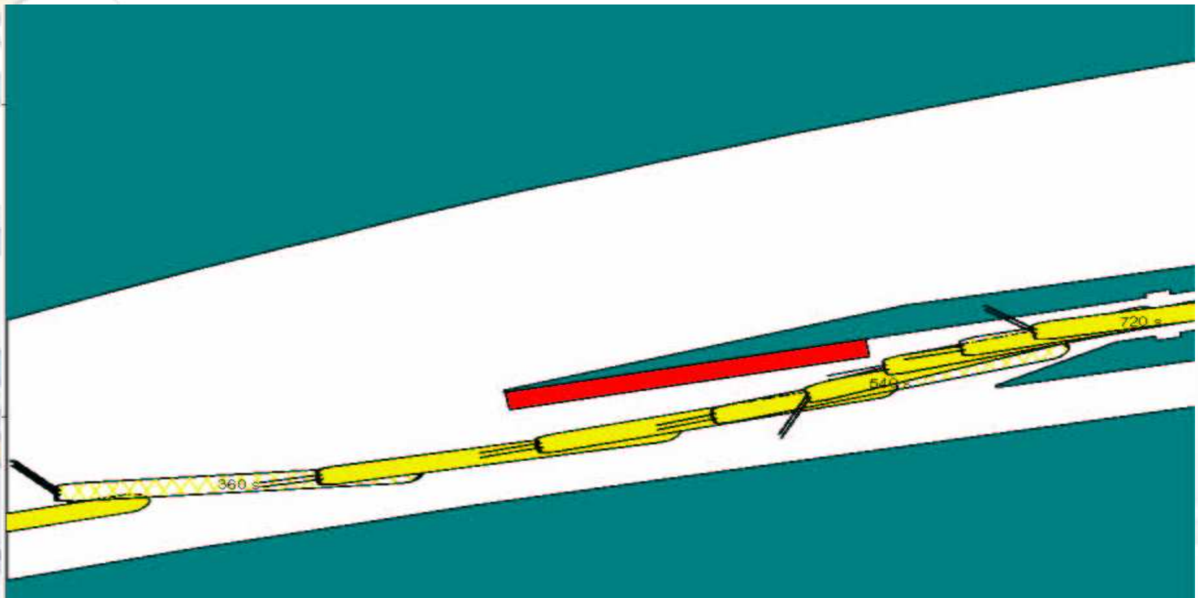


Robot to measure automatically
the velocities distribution in the flow



Upstream wall

Simulation navigation (ALKYON)



The multi-approach study of the ports layout for the new lock enabled the design of a adequate solution regarding both navigation fluidity and safety with only insignificant impact on flood levels

Hydraulic studies Recommendations

Improvement of the numerical scheme neighbourhood of the structures

Numerical modelling

Physical modelling

Management of the boundaries conditions

Geographical spreading
Unsteady flow simulations

3D modelisation for complex situations
Public relations

Composite modelling
Conclusions

The most common theoretical combination during the design process is :

- Analytical models at early design stage, so as to know the feasibility of widely different solutions;
- Numerical models at detailed design stage to get a refined solution;
- Physical models for final design stage to confirm interactions.

The added values of the composite modelling are the limitation of the parasite effects, guaranty the precision and accurate way of the design, flexibility, cost efficiency, teaching and efficient mean of communication which improve multidisciplinary approach.

Thank you for your attention

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