PIANC Workshop
13-14th September 2011

Part 5: Mooring Forces & Vessel behaviour (in locks)

Experience in The Netherlands

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(per Aug'11 at BMT ARGOSS)
The Netherlands

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Developments in Netherlands

- Historical levelling techniques in NL
- Lock modelling in the 20 century (LOCKFILL)
- Demand for modelling of complex levelling system (e.g. for Canal Seine Nord Europ)

Modelling chain developed by Alkyon/Arcadis:

1. 1-D flow model for simulation of high lift locks
2. 2-D flow model of outer harbours and canal
3. Vessel response in time domain: motions and mooring forces in and around lock.

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Lock levelling in The Netherlands

- Centuries of lock building experience
  (wood, brick, concrete, sheet pile, etc.)
- Small and large locks, low lift (few meters)

Leveling system in head (in gate, culverts, lifting):

- ➢Flow and turbulence in lock chamber
- ➢High mooring forces and ship motions
- ➢Controlled by (slow) opening speed of valve
  (tranquility in lock depends on lock operator)

Example of old levelling system 1

Leveling through opening in the lock gate:

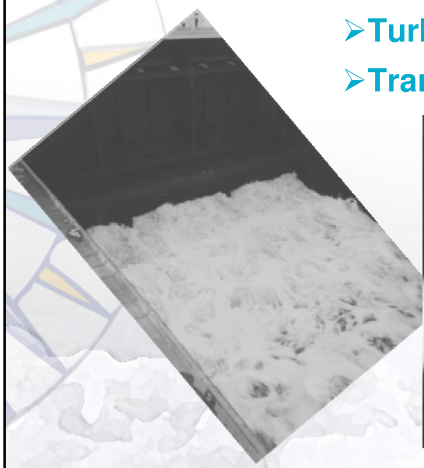
- ➢Turbulence
- ➢Motions
- ➢Line forces

Example of old levelling system 2

Leveling through culverts in the lock head:
- ➢Turbulence
- ➢Flow
- ➢Motions
- ➢Line forces

Example of old levelling system 3

Filling by lifting of the gate:
- ➢Turbulence and
- ➢Translatory waves



Lock levelling model LOCKFILL

Developed by Delft Hydraulics (1990-1995):

✓For Ministry of Transport, Public Works and Water Management in the Netherlands

✓Verified by model test at Delft Hydraulics

Present status:

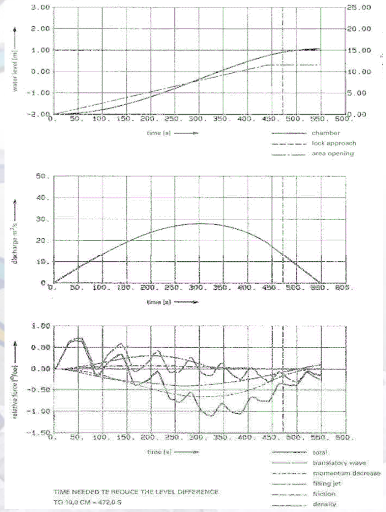
➢Maintained and applied by Delft Hydraulics

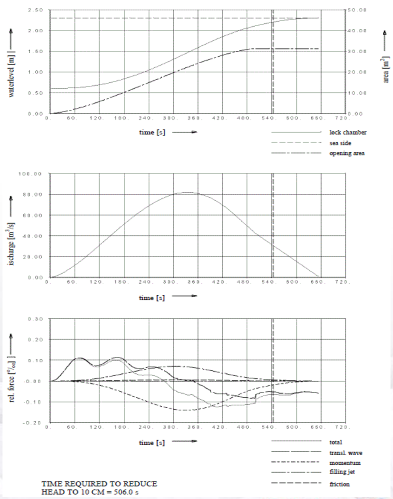
➢Design/verification tool for locks for Ministry of Infrastructure & Environment

Main features of LOCKFILL

1. Simulation of the leveling (filling/emptying) process of the lock chamber in time domain:
   - ➢ Water levels
   - ➢ Discharges
2. Longitudinal forces on the vessel:
   - ➢ Translatory wave in lock chamber
   - ➢ Momentum decrease over the vessel length
   - ➢ Jet of filling flow at bow
   - ➢ Friction along the vessel hull

The LOCKFILL results

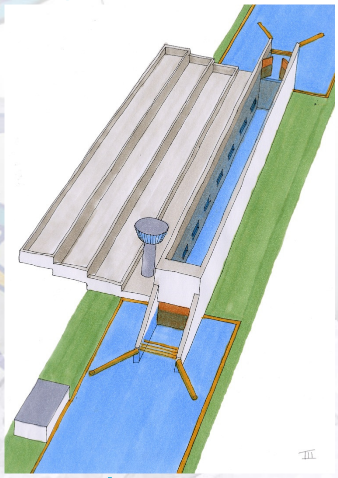




Limitations of LOCKFILL

- ✓ Filling at the lock head
  (no side-filling or bottom filling)
- ✓ Maximum lift of about 4 m
  (not verified for higher lift heights)
- ✓ Through and at Delft Hydraulics
  (No commercial software package available)

Complex navigation locks (e.g. for Canal Seine Nord-Europ)



The locks characteristics:

✓Lock chamber 200*12.5 m;

✓Lock lift up to 30 m;

✓Up to 5 saving basins;

✓Levelling-time: <15 minutes;

✓Water level inclination <0.1%.

Need for:

➢New modelling approach

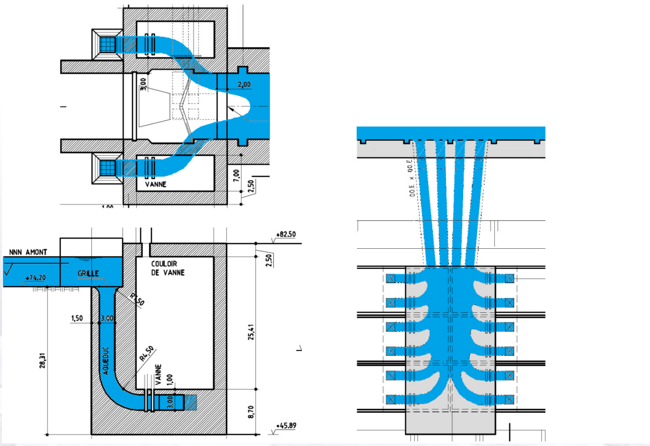
Design philosophy for levelling

1. Levelling through bottom-filling
2. Minimise the inertia of the water in the culverts
   - ➢ short distances
3. Minimise the energy losses in the culverts
   - ➢ culverts internally fluent (gradually changing cross-sections, no sharp corners, no lee areas with turbulence);
4. Discharges controlled by (partly) opened valves
   - ➢ Balanced valve opening and closing strategy to minimise the water level inclination

Minimise energy losses in culverts

Apply:
- Gradual changing profiles
- Large radius

Avoid:
- Sharp corners
- Lee areas



Mathematical modelling for CSNE

Integrated modelling (in time-domain) in 3 steps:

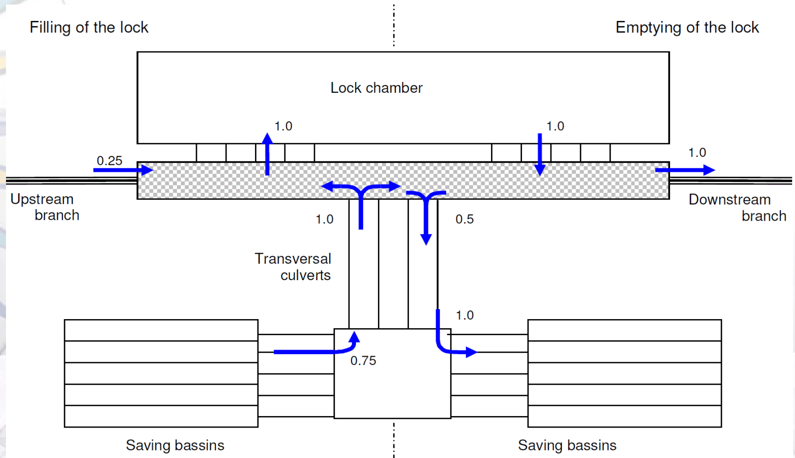
1. Filling en empting of lock with saving basins
   - Sensitivity runs (hydraulic losses in culverts)
   - Valve operation strategy
2. Water-level inclination and flow velocity in:
   - lock chamber
   - lock outer-harbours
3. Mooring forces and vessel behaviour in:
   - lock camber and
   - lock outer-harbours

Model for lock-levelling

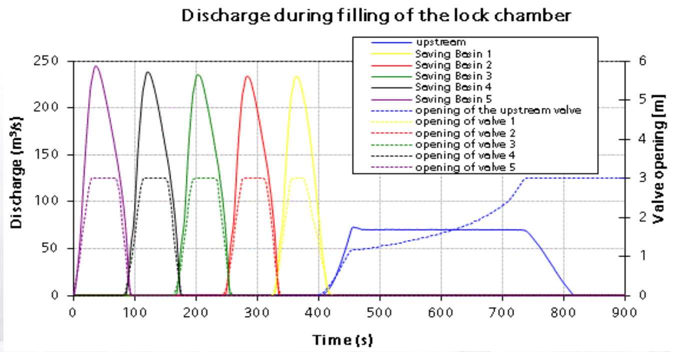
1-D Flow model InfoWorks-RS (from HR-Wallingford):

- Outer harbours with canal section
- Lock chamber
- Double bottom with openings
- Short culverts with valves in lock heads
- Culverts to saving basins
- Saving basins with valves

1-D Flow model: elements and applied energy loss-coefficients



Lock with 30 m lift and 5 basins
Valves and discharges during filling



- Filling from basins with over 200 m3/s
- Filling from canal at 70 m3/s

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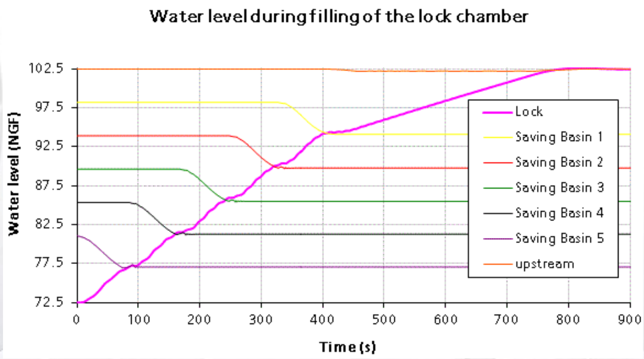
Lock with 30 m lift and 5 basins
Levels during filling



- 5 basins filling each 5.5 m in 90 s (22 m in 450 s)
- Remaining 8 m filled from the canal in 350 sec

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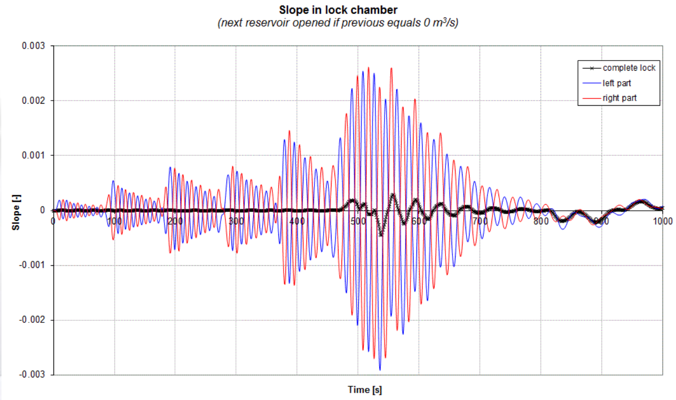
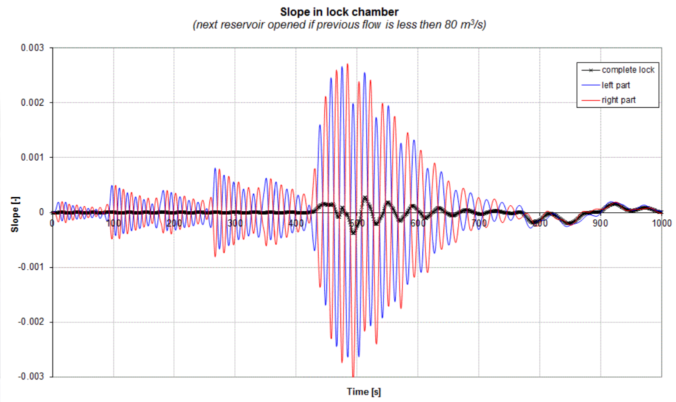
Water-level inclination: next valve open at 0 m3/s



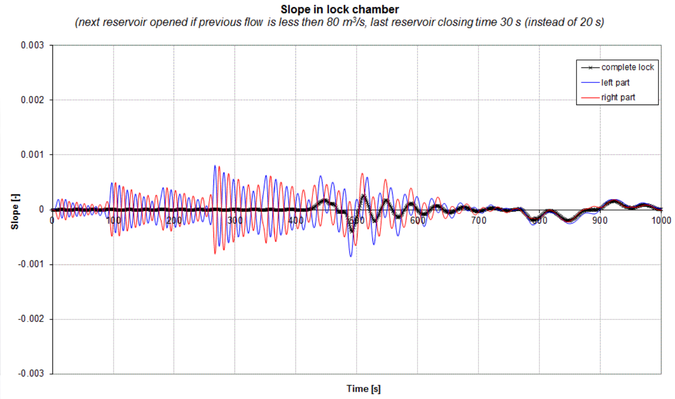
- Inclination increases leveling 5 basins: > 0.01%
- During leveling canal: >> 0.01%

Water-level inclination: next valve open at 80 m3/s



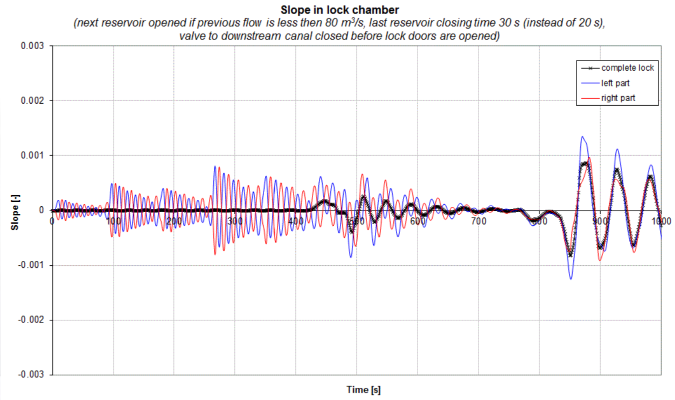
- Acceptable inclination leveling 5 basins : < 0.01%
- During leveling canal: >> 0.01%

Water-level inclination: slow closure of valves of 5 basin



- Acceptable inclination leveling 5 basins : < 0.01%
- Acceptable inclination leveling canal: < 0.01%

Water-level inclination: valves to canal closed before opening of gate



- Acceptable inclination during 5 basins : < 0.01%
- During leveling from canal: > 0.01%

Valve opening rules

Valve	Rule	Condition for Emptying Lock3				Valve movement
Reservoir 1	open	starts at a certain time				0.15*
	close	F1 <135			LC-R <1	0.15
Reservoir 2	open	F1 =80	LC < 100.36	LC > 96.07		0.15*
	close	F2 <135			LC-R <1	0.15
Reservoir 3	open	F2 =80	LC < 96.07	LC > 91.79		0.15*
	close	F3 <135			LC-R <1	0.15
Reservoir 4	open	F3 =80	LC < 91.79	LC > 87.5		0.15*
	close	F4 <135			LC-R <1	0.15
Reservoir 5	open	F4 =80	LC < 87.5	LC > 83.21		0.15*
	close	F5 <165			LC-R <2.35	0.075
DS	open_1	F5 =80	LC < 83.21	LC > 78.93	Fds <70	0.04*
	open_2	Fds >0	Fds <70			0.04*
	stop	Fds >70				0
	close	Fds <40	LC-ds < 0			0.15

** starts with a decelerate valve velocity*
F1 = flow at valve of reservoir or canal, with corresponding number 1(or 2, 3, 4, 5, ds, us)
LC = lock chamber level
R = corresponding reservoir or reach level
DS = downstream
US = upstream

Vessel response on levelling

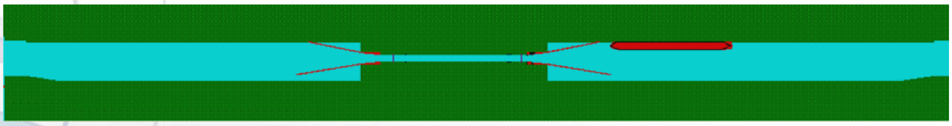
- Hydraulic forces on vessel
- Mass and added mass of the (moored) vessel
- Vessel in (elastic) mooring lines
- Pretension in mooring lines
- Dynamic system (mass–spring system)
- Response of vessel
- Forces in mooring lines

Applied model:

➢SHIP-MOORINGS (developed at Alkyon/Arcadis)

Moored ship response

SHIP-MOORINGS simulates the 3-D motions of the vessel, the mooring forces and the fender forces.

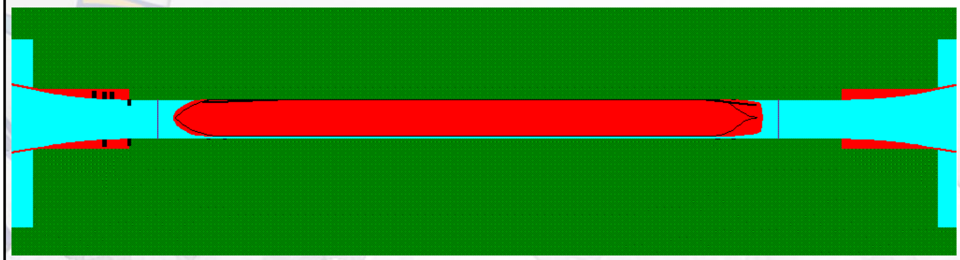


Model input is a mathematical description of:

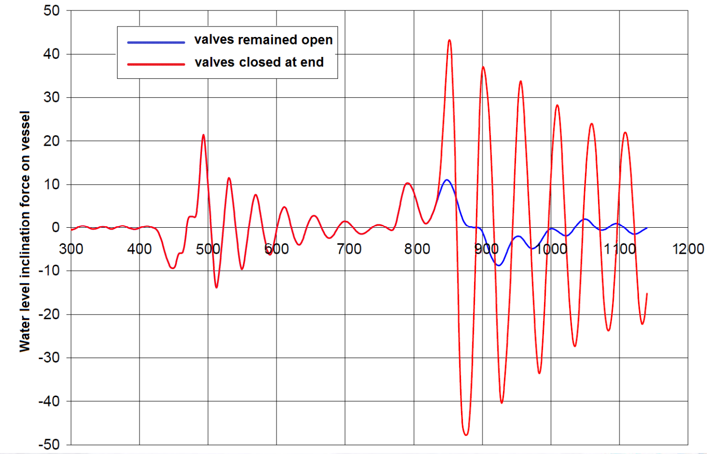
- •Vessel (mass and hydrodynamic-reaction forces)
- •The environment (plan and water depth)
- •External (hydraulic) forces
- •Mooring lines (with or without pretension)

SHIP-Mooring model of lock chamber

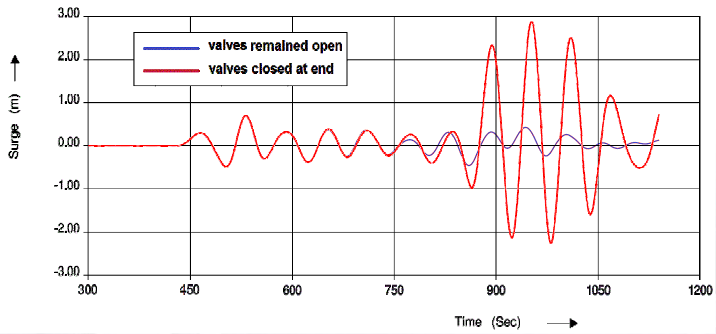
CEMT Class Vb vessel moored in lock chamber



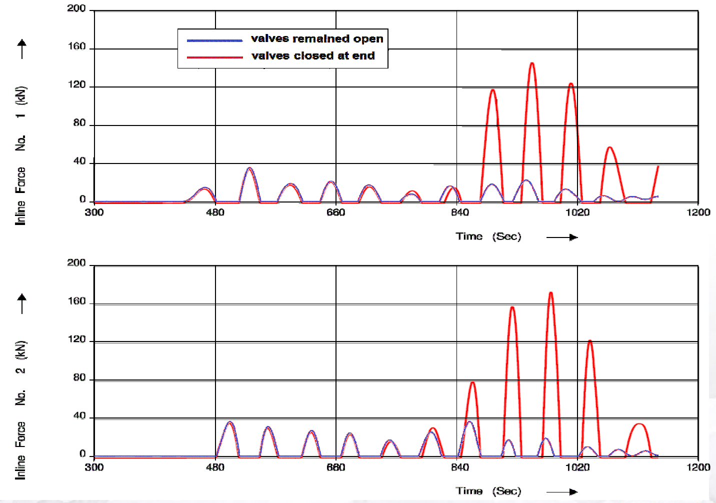
Forces on vessel in lock
From water level inclination



Surge motion of vessel in lock

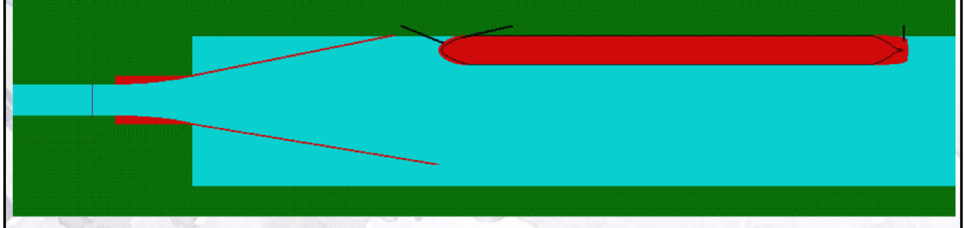


Mooring line forces of vessel in lock



SHIP-Mooring model of lock outer harbour

CEMT Class Vb vessel moored in outer harbour

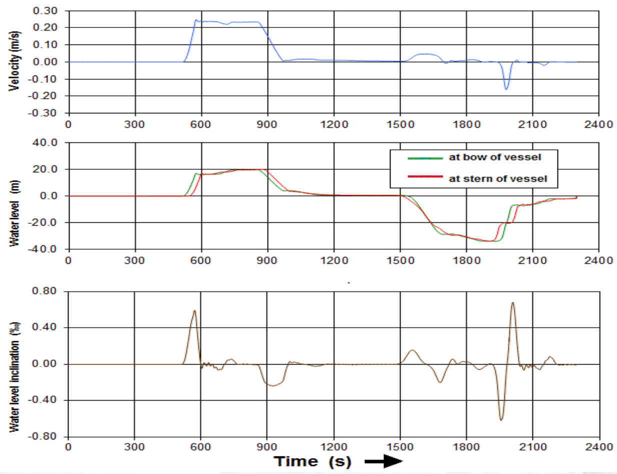


Lock levelling induced water motion in outer harbour

Flow velocity during leveling (Delft3D model)

Water level at bow and stern

Water level inclination



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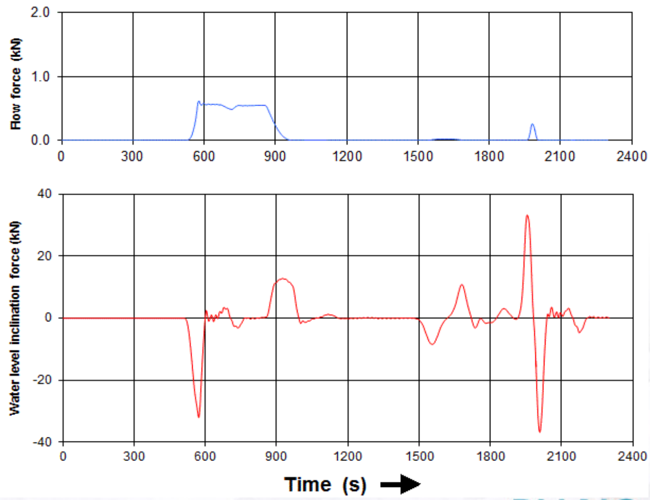
Forces on vessel in outer harbour

Friction force

Water level inclination force



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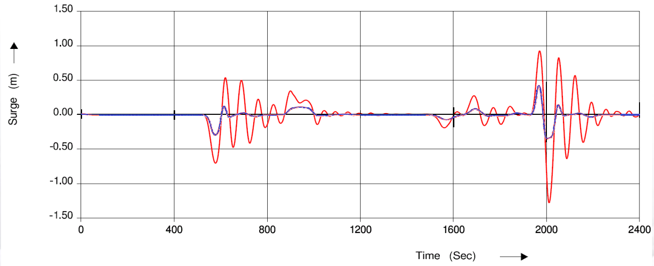
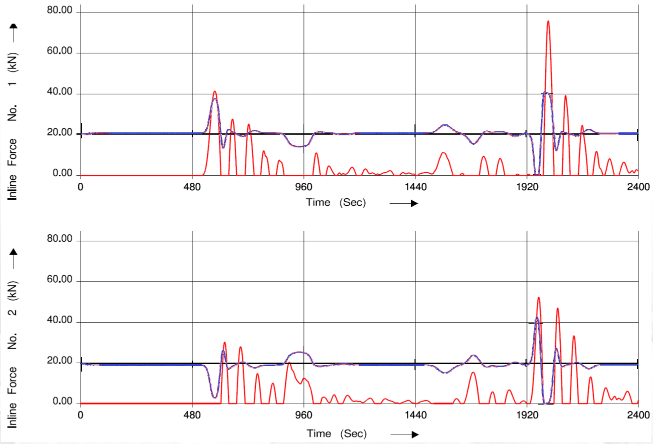
Surge motion of vessel in outer harbour

without
and
with
pretension



Mooring line forces of vessel in outer harbour

without
and
with
pretension



Summary and conclusions 1

- 1-D and 2-D flow modelling and simulation of moored vessel was successfully used for simulation of vessel behaviour due to lock levelling
- Discharge, water level, water-level inclination, levelling time, vessel behaviour and mooring forces were simulated
- Results appeared in line with physical model tests at Sogreah, France; see: Pianc-WG-locks(2009).

Summary and conclusions 2

- Low hydraulics losses in culverts enable the high discharges required for fast levelling
- The water-level inclination and ship motions appeared very sensitive for valve opening and closing speed and procedure
- Pretension in mooring lines significantly affects the ship motions

Thank you for your attention.

Questions?

My question to you:
Will this knowledge
take you somewhere?