INNOVATION
IN NAVIGATION LOCK DESIGN

PIANC Report n° 106 (2009)

Port Infrastructure 2010 - TU Delft, NL
June 2010

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WG29: Lock Innovations

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LOCK INNOVATIONS

The PIANC report n° 106 (2009):

- Complement to PIANC 1986 report.
- Targets: innovations and changes occurring since 1986

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NEW LOCK INNOVATIVE TOPICS

- Hydraulics (filling and emptying),
- Operations and Maintenance,
- Environmental,
- Design (concrete, foundation, gate,…),
- Construction Modes,
- Equipments,
- …..
- Design concept : Cost-Effective, Reliable,….

WG29 - LOCK INNOVATIONS

Major changes in design since 1986 concern:

- Maintenance and Operation aspects,
- New goals at the conceptual design stages of a lock
  - ➔ RELIABILITY , LIVE CYCLE COST, ...
- Renovation and rehabilitation of existing locks are also key issues for the future.

DESIGN PRINCIPLES

1. "Risk based design" versus "Deterministic approach"

2. "Life cycle cost optimisation" versus "Least construction cost"

3. Use of "Numerical Modelling" as design tool (combined with physical model)

Complementarities between modeling

STEP	PHYSICAL MODEL	NUMERICAL MODEL
1	Definition of the problem	
	Identification of the essential acting forces	
2	Formulation of similarity requirements	Formulation of sets of equations
3	Formulation of boundary conditions	
4	Construction of a model	Development of a numerical solution scheme
5	Calibration of the model	
	Variation of roughness	Variation of coefficients
6	Measurements & solution	Calculation and solution
7	Optimization of the solution according to problem formulation	
	Model geometry variations	Variation of input data
8	Transfer of results from model to prototype	
	and examination by field measurements	

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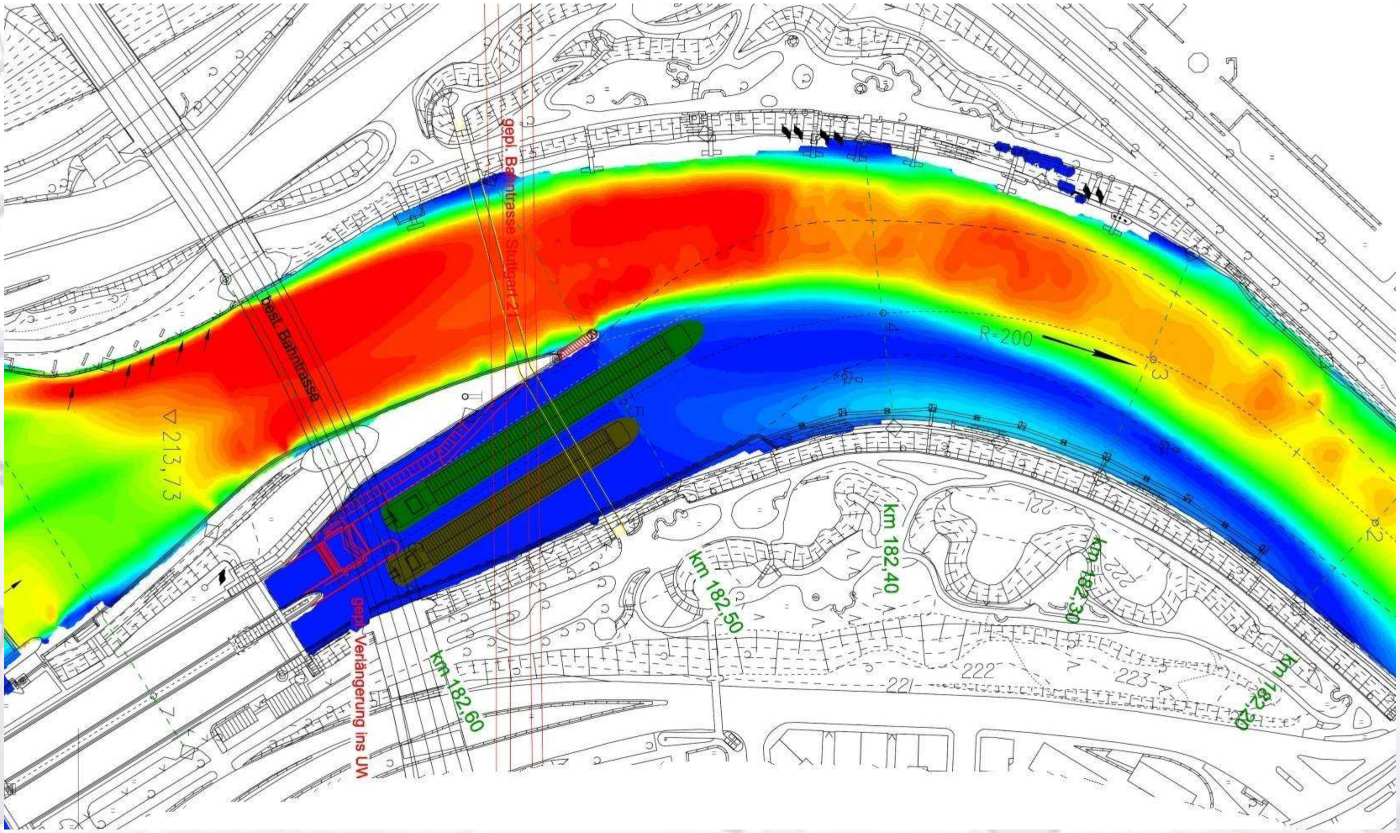
Classification of numerical models

- ➔ **1D-models: networks of filling and emptying systems (full lock cycles, mass balance computations)**
- ➔ **2D-models, depth averaged: Inlet-outlet areas, maybe chamber sloshing (lock cycles)**
- ➔ **3D-models with single fluid phase: Special parts of the filling-emptying system**
- ➔ **3D-models with multiple fluid phases: Flow in chamber, water saving basins, inlet-outlet areas**

Two dimensional models



Large scale flow modelling
downstream of a weir

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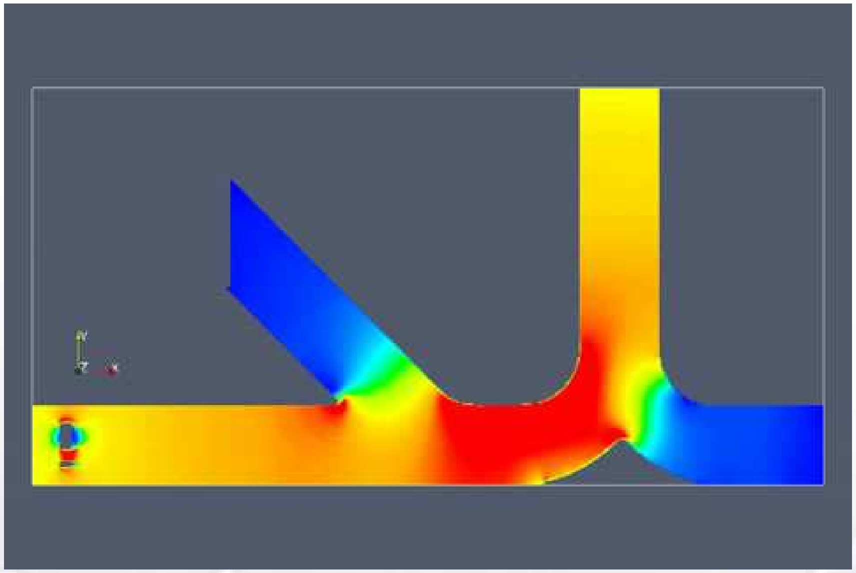
Possible lock modeling strategy

- 3D-CFD model (or hydraulic model) for local loss coefficients



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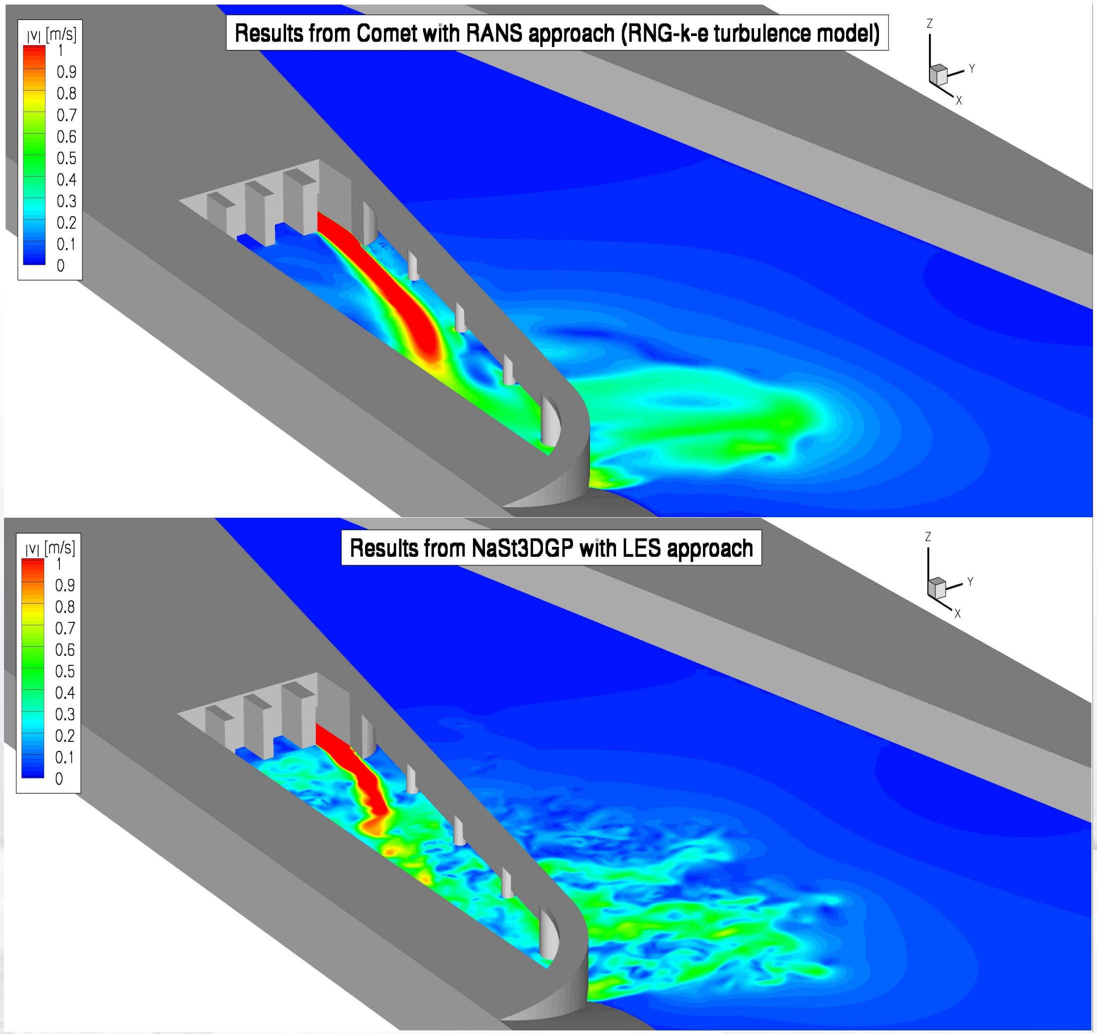
Turbulence model: RANS or LES?



InCom WG 29 CONCLUSIONS

Current Trade off problems in Lock Design:

➔ "HIGH RELIABILITY" is often associated with "PROVEN TECHNOLOGIES" (in Lock Design)

If true ➔ Is it a place for innovation in lock?

WG29 ➔ Yes. Innovation is required to reach highly reliable infrastructures, to reduce cost (construction mode), fulfil new requirements (fast locking), non standard dimension,…

Do not be afraid by innovation. ➔ Promote innovation.

➔ **"RELIABILITY" versus "COST" (in lock design)**

Lock design is highly "Project Dependant".

Ex: "Panama Canal" versus the "Renovation of a small pleasure lock in Finland"

INNOVATIONS IN LOCK DESIGN

→ FEW EXAMPLES

PROJECT REVIEWS

- Innovative features or unusual aspects.
- review various types of innovation and state of technology.
- Illustrate the subjects covered in the report.

UK - Falkirk Wheel (10-04)

Areas of Innovation

Hydraulic	O & M	Environ	Design / Construct	Misc

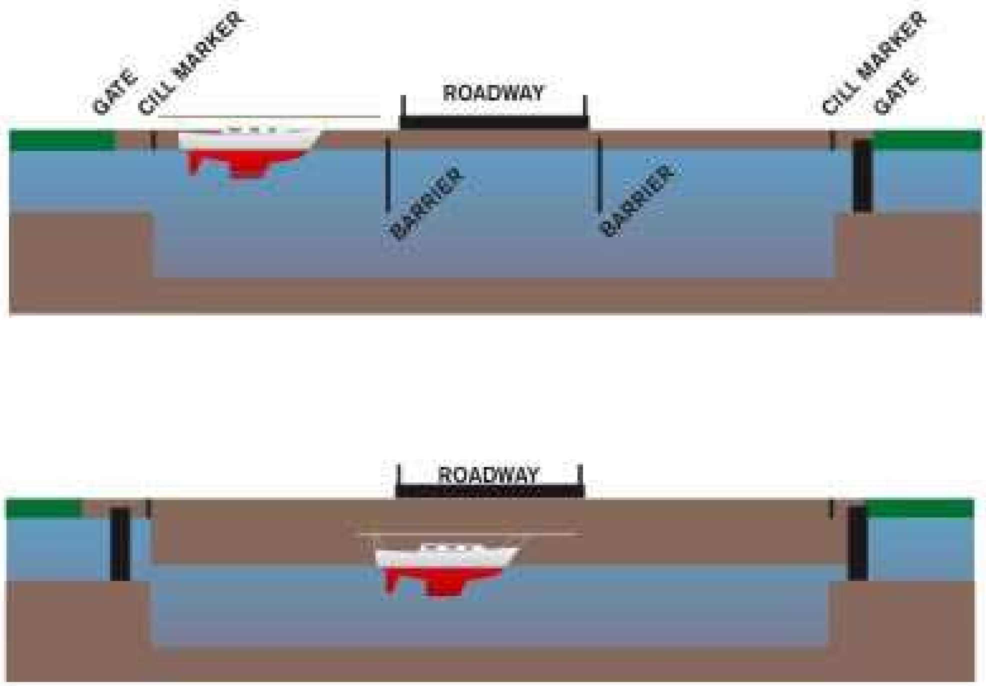
Lock Dimensions

Length	22	Lift:	33.5m
Width:	6	Depth	1.5

D = 35 metres.

No actual lock (a ship lift), but characteristic for its principle, its aesthetic design and its multiple purpose, which includes tourism.

UK - Dalmuir Drop Lock (10-03)



Areas of Innovation

Hydraulic	O & M	Environ	Design / Construct	Misc

Lock Dimensions

Length		Lift:	
Width:		Depth	

An innovative use of existing techniques can be seen at the Drop Lock. Vessels are temporarily lowered, just to cross the road underneath.

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FIN - Juankoski Canal (4-01)

Areas of Innovation

Hydraulic	O & M	Environ	Design / Construct	Misc

Lock Dimensions

Length	35 m	Lift:	6 – 6.5 m
Width:	8 m	Depth	2.4 m

Where locks are built in rock, concrete walls do not always need to be used.

In those cases it is possible to use only a floating pontoon to moor the ships during lockage.

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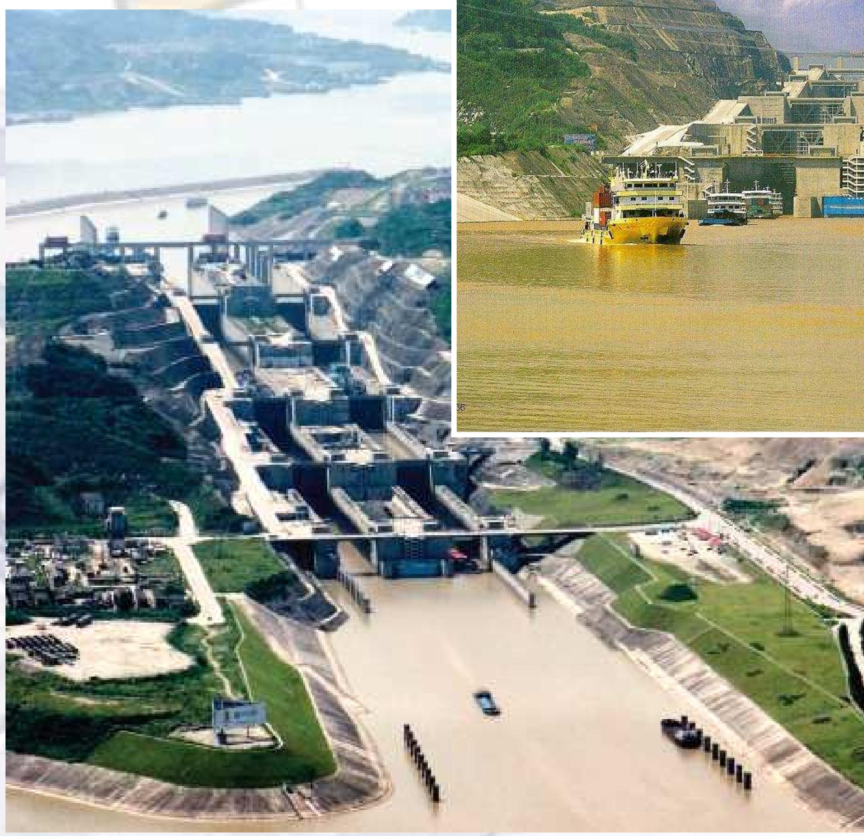
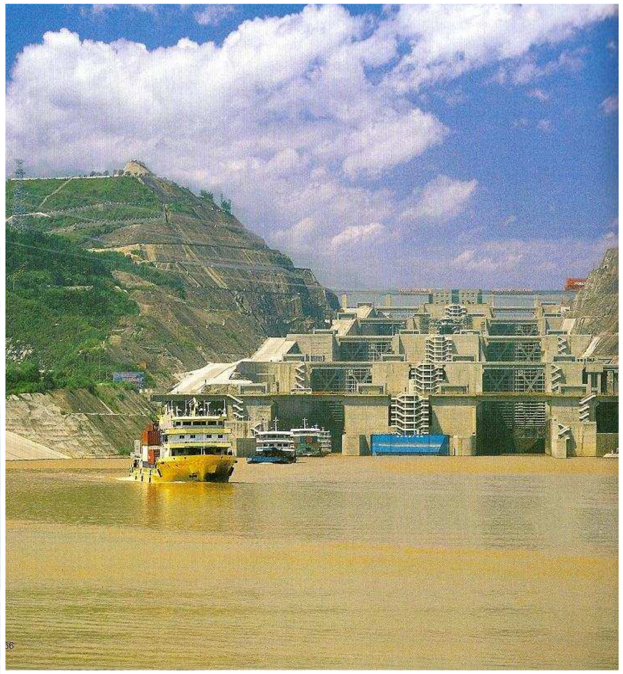
China – Three Gorges





Areas of Innovation

Hydraulic	O & M	Environ	Design / Construct	Misc

Lock Dimensions

Length:	1,621.0 m	Lift:	113.0 m
Width:	34.0 m	Depth:	5.0 m

With a total lift of 113 m and a max. water head of 45.2 m, the Three Gorges locks are in height the largest locks in the world.

Apart from its dimensions, also the Filling and Emptying system and the prevention of Cavitation are major innovative aspects.

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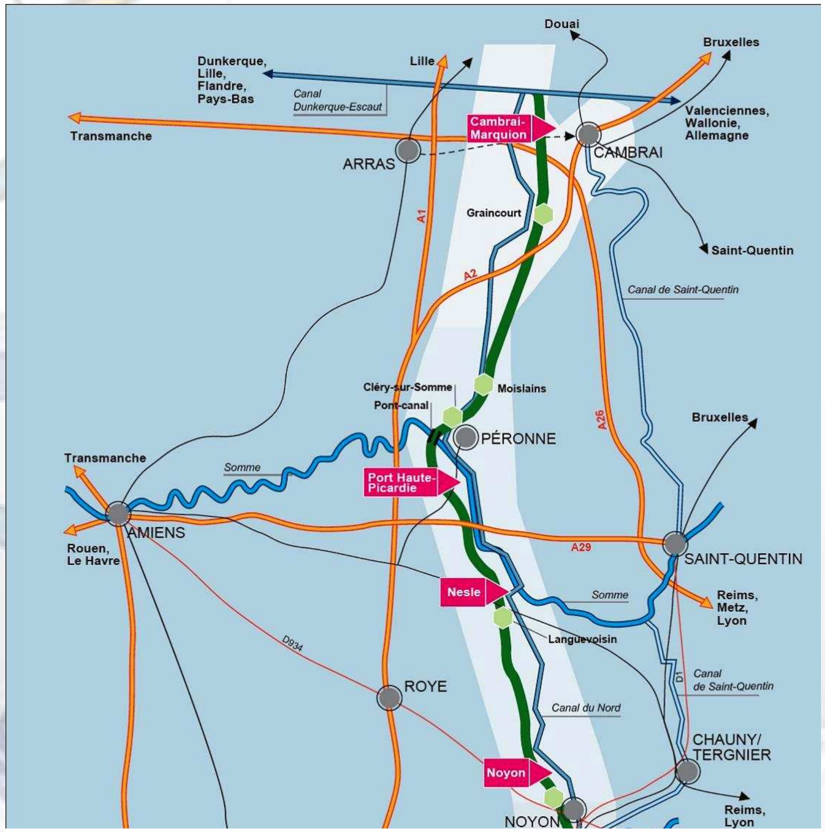
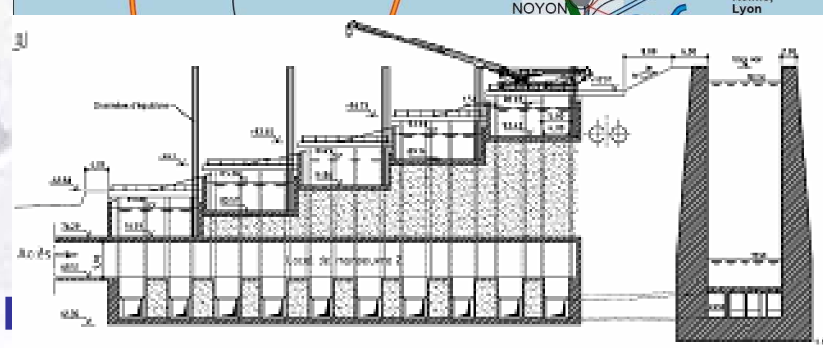
France - Seine-Nord Europe





Areas of Innovation

Hydraulic	O & M	Environ	Design / Construct	Misc

(Lock) Dimensions

Length	106 km	Lift:	15 – 30 m
Width:	12.5 m	Depth	

A new canal of 106 km long with 7 standardized locks will become an important connection between France and Northern Europe.

The major challenge in this project is the Water Resources Management.

- Water saving basins
- Pumping plants
- Watertight canal

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Panama - Canal Expansion

Areas of Innovation

Hydraulic	O & M	Environ	Design / Construct	Misc

Lock dimensions

Length	1281 m	Lift:	27m
Width:	55 m	Depth	18.3 m

Third Lock Project in Panama

- Three-step locks,
- Each with 3 water saving basins
- Side F/E system
- fresh and salt water on lock limits
- 365 / 24 / 7 uninterrupted use

Germany

Hohenwarthe

An important example of structural innovations is the development of monolithic locks.

At the Hohenwarthe lock this solution is used for the 250 m long bottom plate.

Kaiserlock

Concept of magnetic mooring system

(also in use in N-Zealand)

Netherlands - Naviduct

Areas of Innovation

Hydraulic	O & M	Environ	Design / Construct	Misc

Lock Dimensions

Length	160 m	Lift:	locking: 1,0 m barrier: 3,2 m
Width:	42 m	Depth	4,5 m

Enkhuizen, the Netherlands.

- A unique combination of a double navigation lock and an underpass for road traffic.
- Mitre gates capable to carry hydraulic loads from both sides

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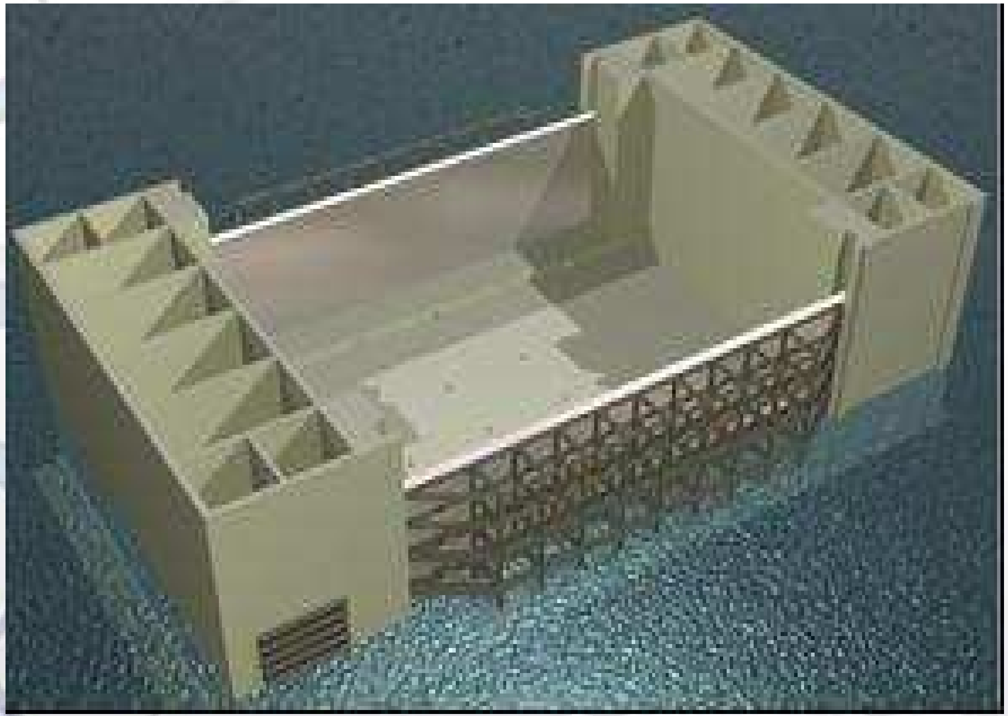
USA – Greenup Lock



Areas of Innovation

Hydraulic	O & M	Environ	Design / Construct	Misc

Lock Dimensions

Length	366 m	Lift:	
Width:	33.5 m	Depth	

Construction Methods in the wet

In the USA many different In the Wet construction methods are in use. Among these are the Float-In and Lift-in techniques of precast elements.

LAYOUT OF HYDRAULIC SYSTEM

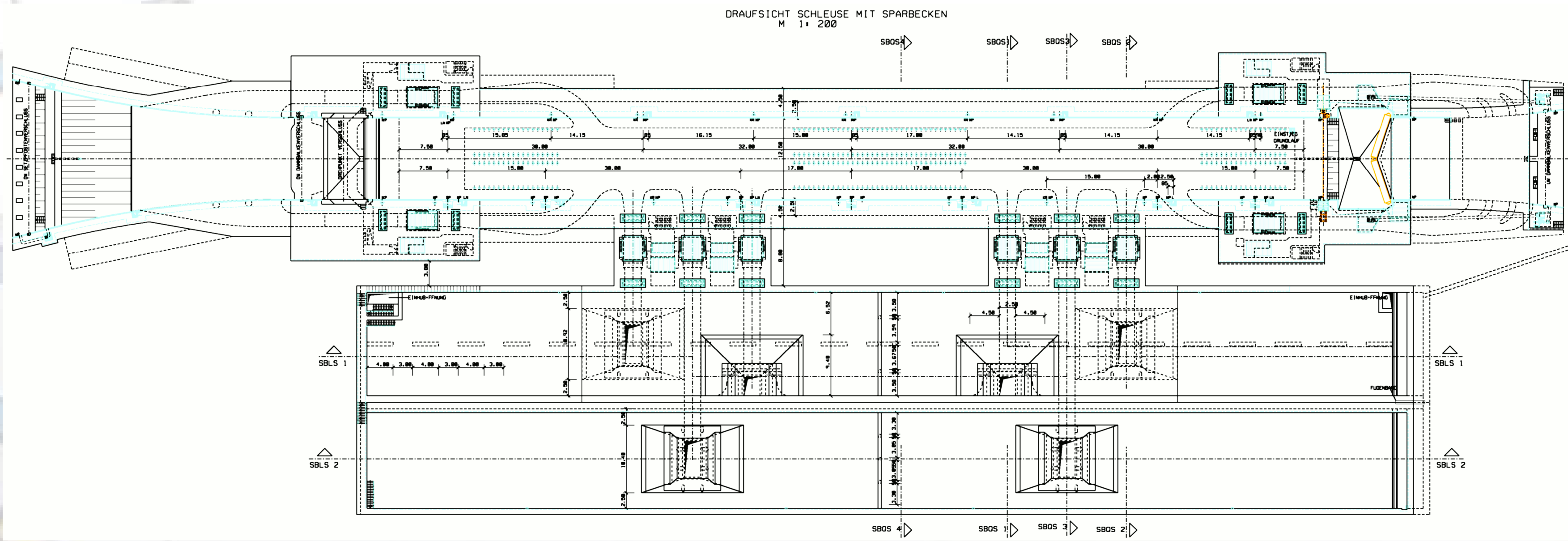
Hydraulic systems for filling and emptying locks can be divided into two types:

➔ *Through the heads*
➔ *Through longitudinal culverts*

Typical layouts of Longitudinal culvert system:

- *Wall culvert side port system*
- *Wall culvert bottom lateral system*
- *In-Chamber longitudinal culvert system (ILCS)*
- *Longitudinal culverts under the lock floor*
- *Dynamically balanced lock filling system*
- *Pressure chamber*

LAYOUT OF HYDRAULIC SYSTEM



Lock with Water saving basins located on the side of the lock
- Standard concept

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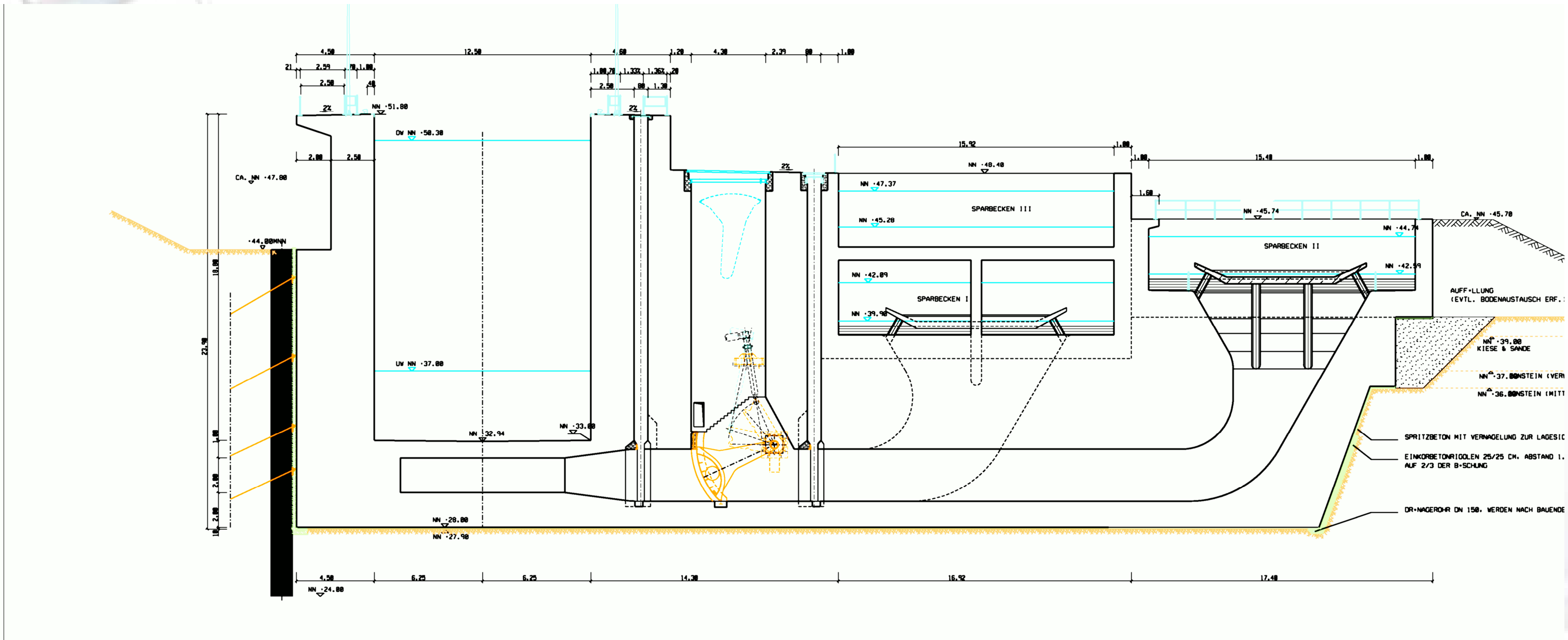
NEW LAYOUT OF HYDRAULIC SYSTEM



Connection of pressure chamber to WSBs basins (upper) and to main chamber (lower)➔ Germany

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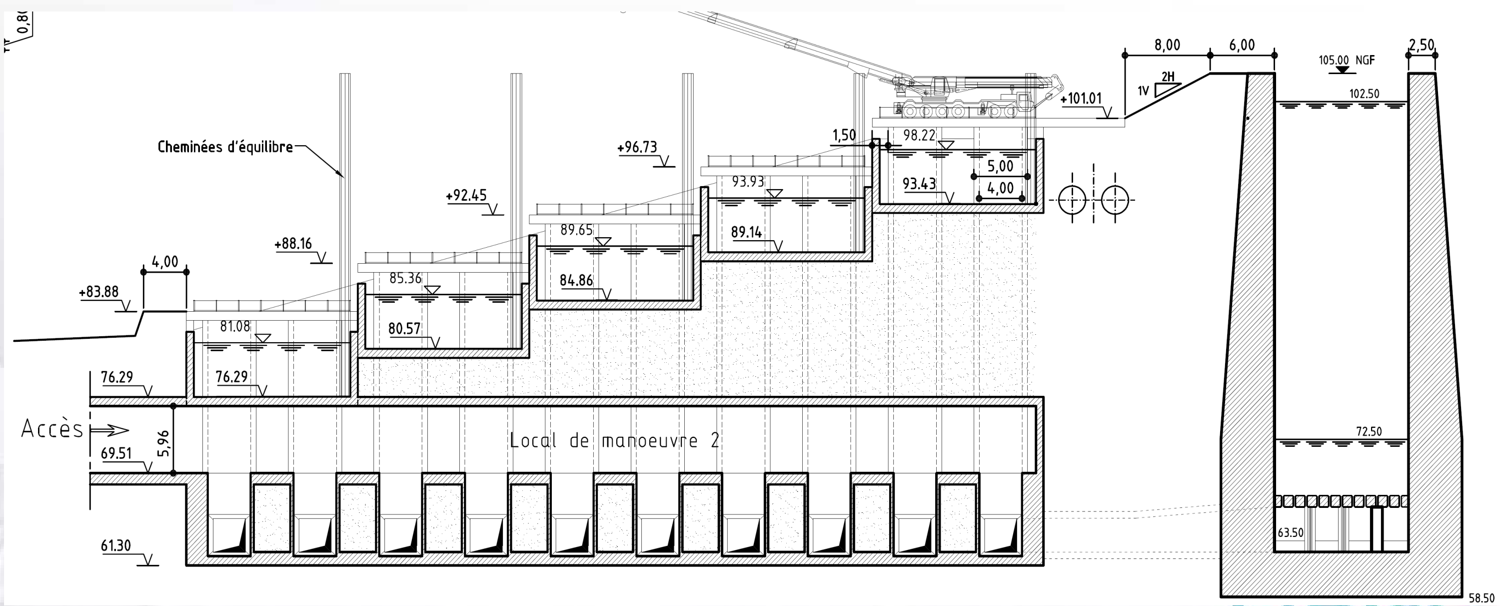
Water Saving Basins (WSB**s**)

Various types
of
Water Saving Basins.



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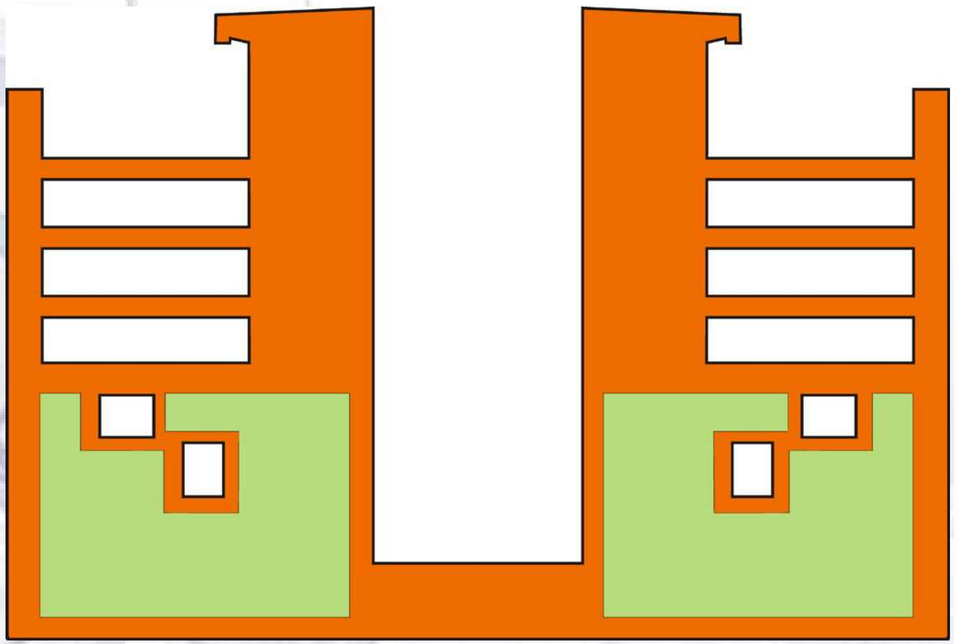
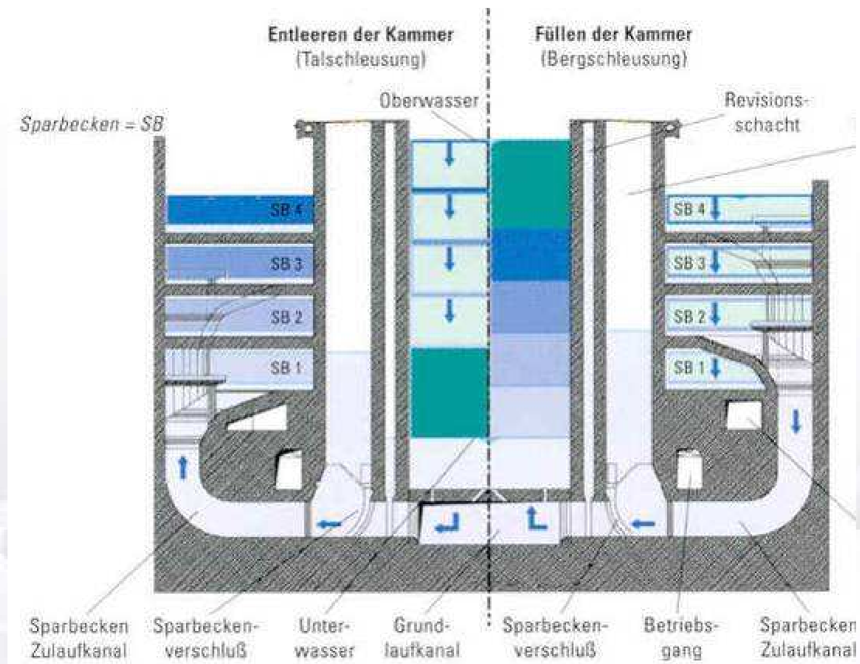
Integrated WSBs

The integrated system which integrates the WSBs in the two side walls, and makes the lock structure more stiff, compact and less land consuming.

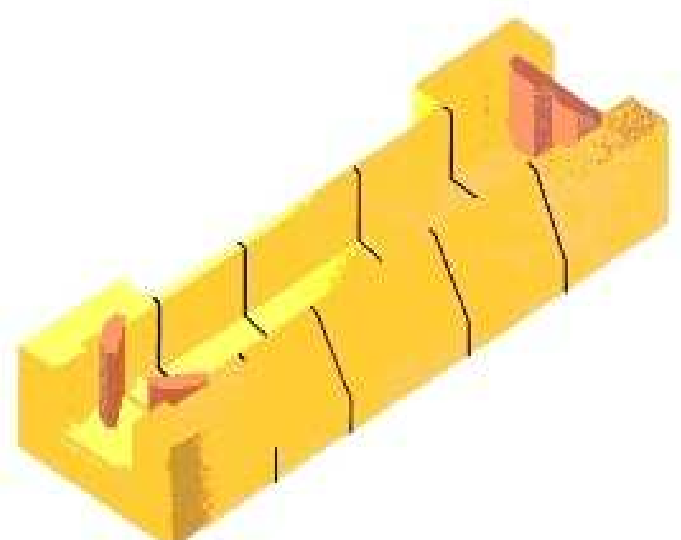




Lock sidewalls with integrated WSBs

Monolith LOCK

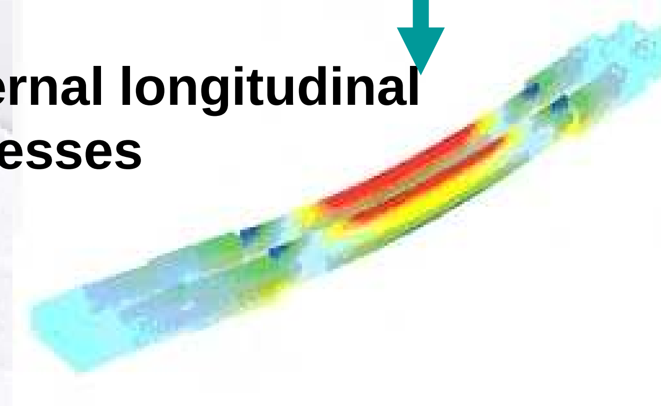
Standard Concept
With dilatation joints



No internal longitudinal stresses

Monolith Concept
Without dilatation joints

Internal longitudinal stresses



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Lock Gates

➔ Focus on

CONTACT PROBLEMS
(By R Daniel)

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CONTACT PROBLEMS IN LOCK GATES

Robert Hooke
1635 – 1703

Hooke's law
1678

Structural mechanics

Heinrich Hertz
1857 – 1894

Hertz theory
1882

Contact mechanics

In today's practice:

- Contact issues are underestimated in gate design, structural are not.
- Majority of gate mechanical malfunctions are contact malfunctions.
- Contact maintenance obstructs the gate operation, costs money and harms the environment.
- We still lack expertise about contact behavior in hydraulic gates.

SIGNIFICANCE OF GATE CONTACTS

Orange Locks in Amsterdam

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SIGNIFICANCE OF GATE CONTACTS

Hagestein Weir on the Rhine

GATE CONTACTS ⟺ SYSTEMS

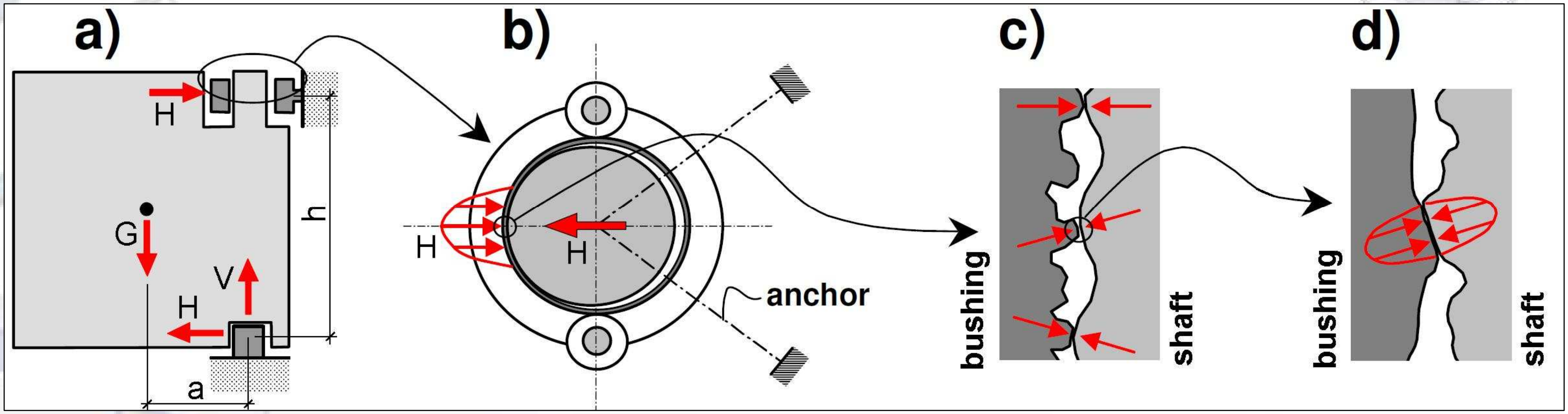
SIGNIFICANT ISSUES:

- Feasibility and durability of the system
- Gate stability and correct load transfer
- Quality of gate motion and tightness
- Reliability of mechanical functioning

TENDENCIES:

- Durability and low maintenance requirements
- Elimination of lubricants (environment)
- Sliding supports instead of rollers and wheels
- Linear and surface contacts instead of pointwise
- Modern synthetic materials and composites

GATE CONTACT LEVELS

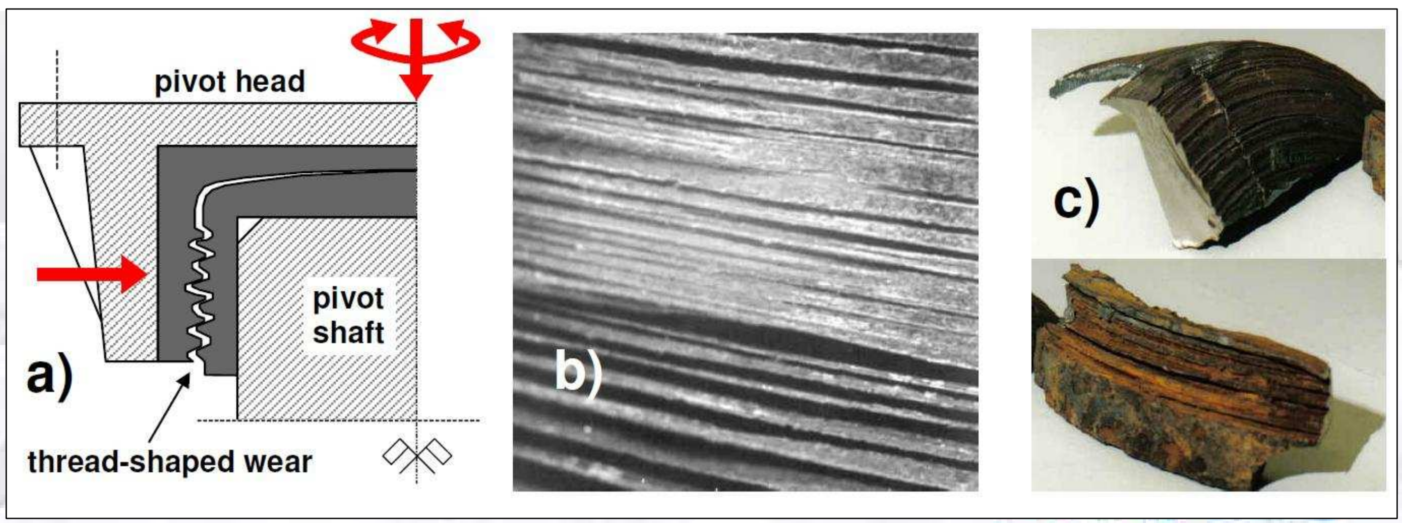


system **component** **segment** **asperity**

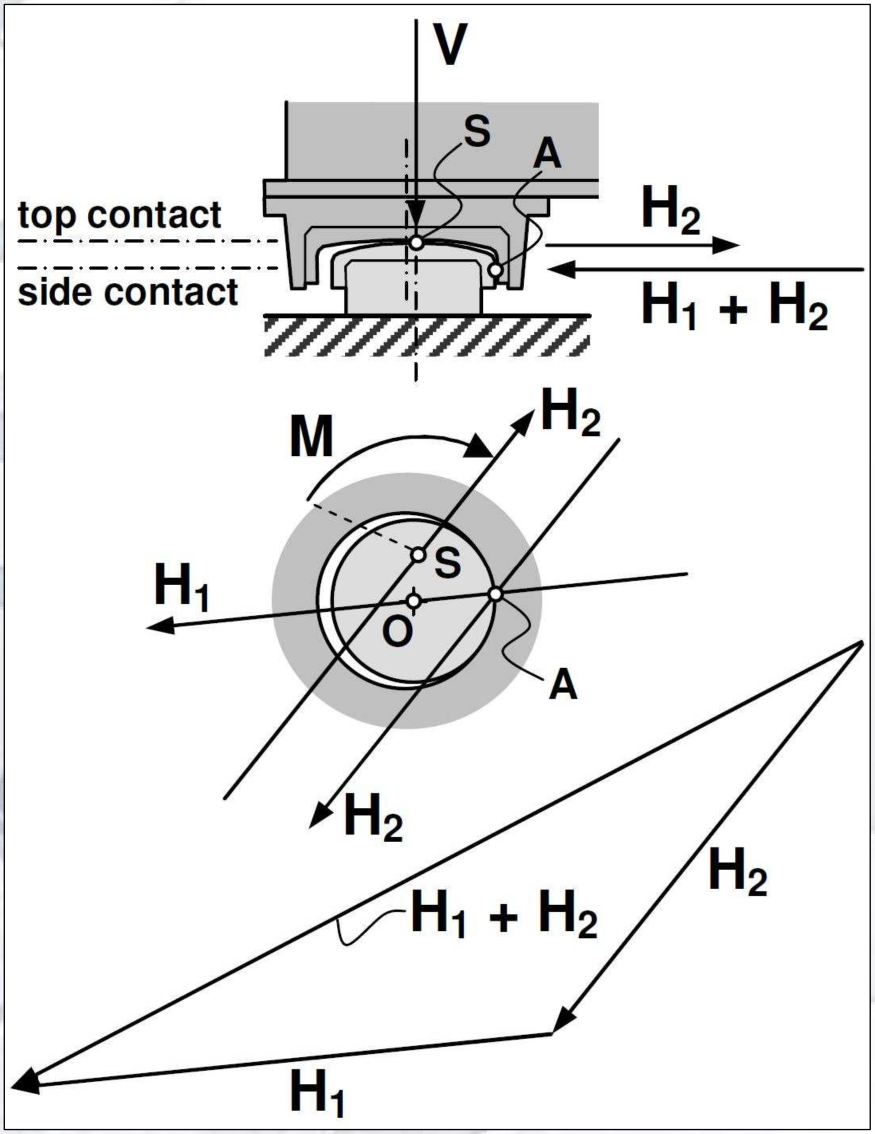
$$V = G$$

$$H = G\frac{a}{h}$$

?



GATE HINGE WEAR PROBLEM



$$V = G \pm (0.1 \div 0.3) \cdot H_1$$

$$H_1 = G \frac{a}{h}$$

$$H_2 = \mu V$$

$$H = \vec{H}_1 + \vec{H}_2 \approx G \frac{a}{h} + \mu V$$

Conclusion:

➢**The actual contact loads in gate hinges are substantially higher than from the statical equilibrium conditions (system level).**

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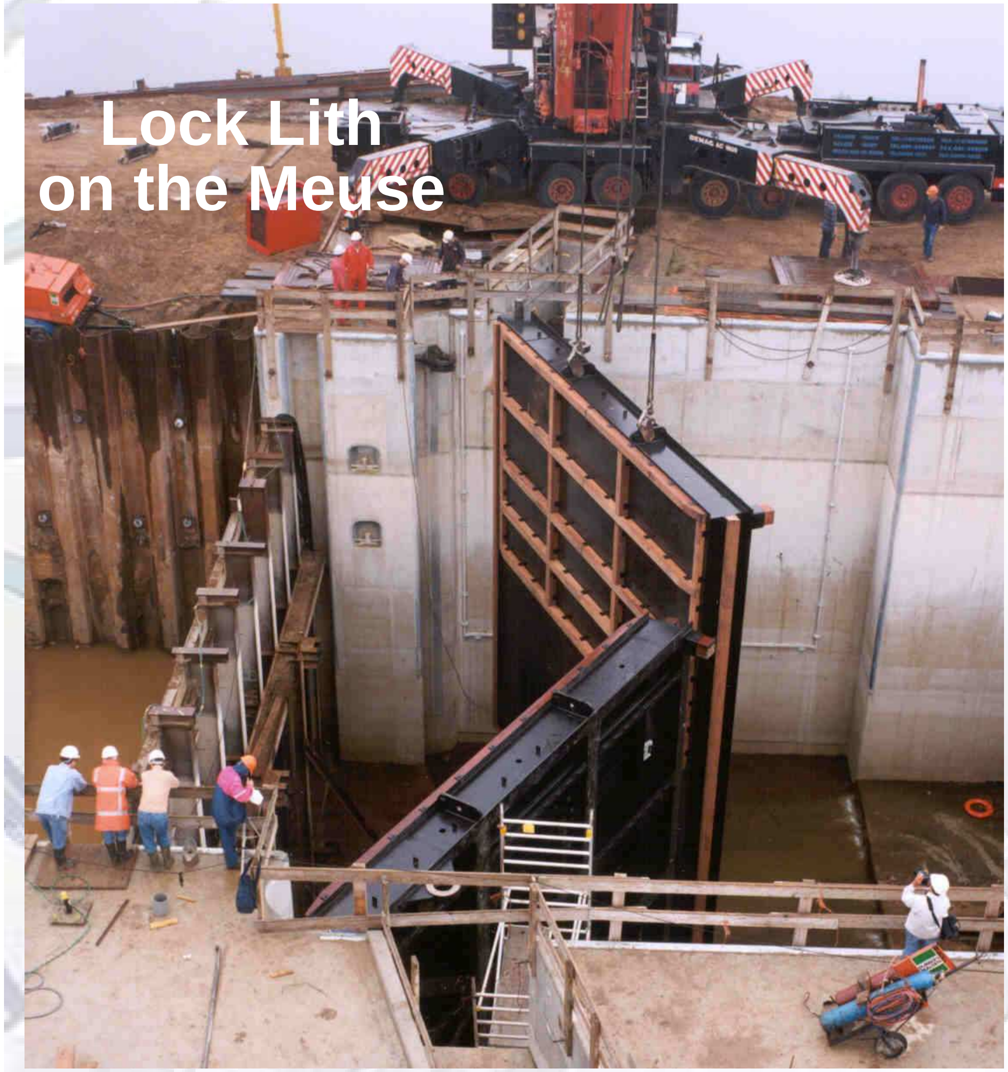
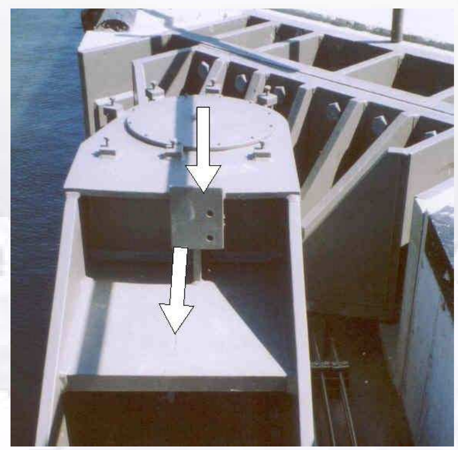
STRUCTURAL SOLUTIONS

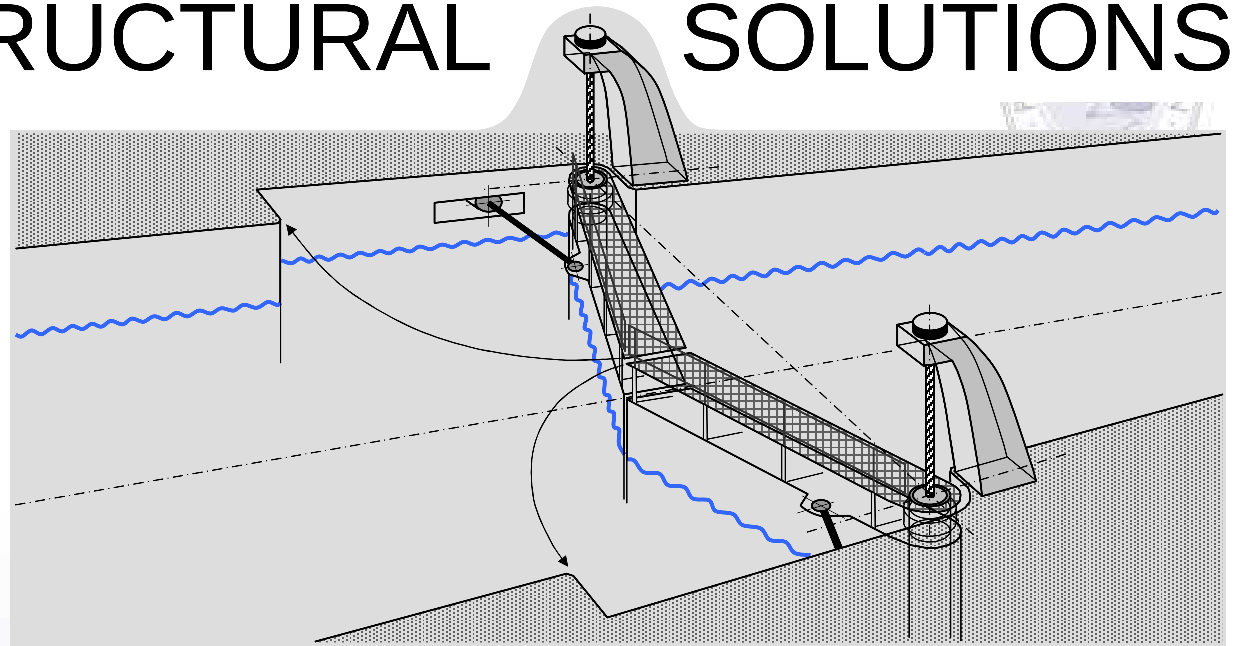


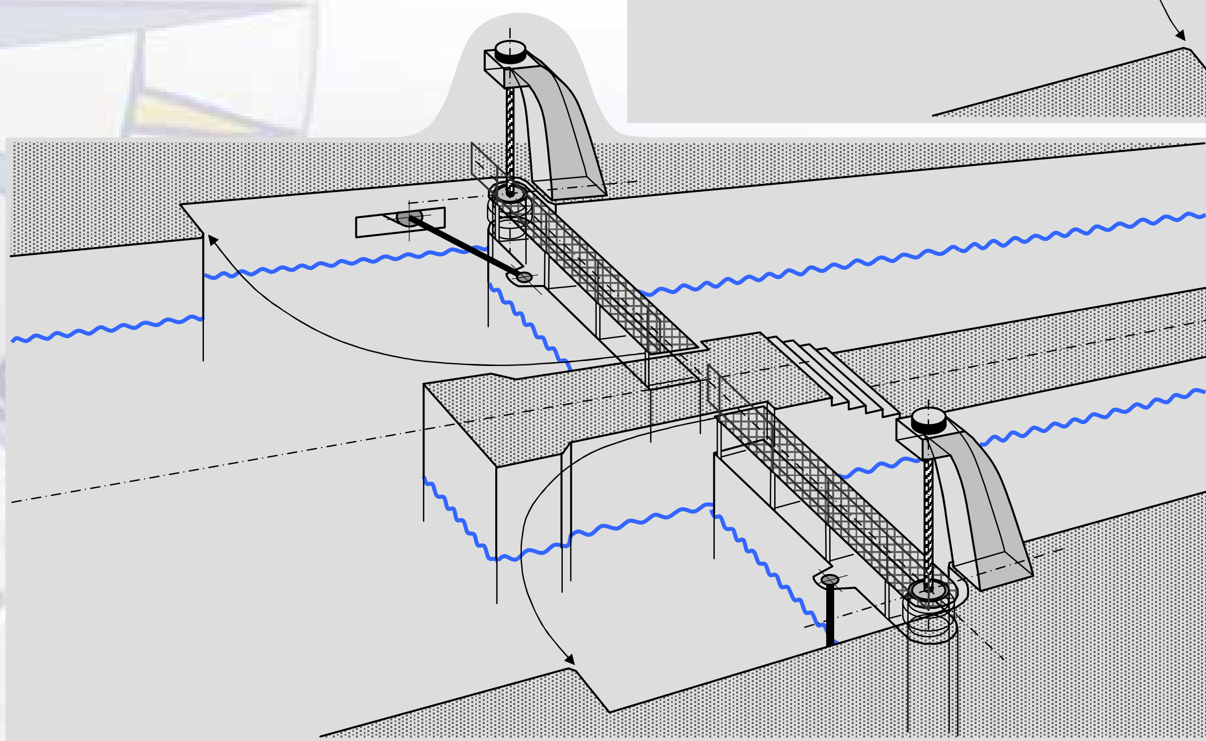


STRUCTURAL SOLUTIONS

SUSPENSION GATES:

mitre gate →





← single leaf gate

Advantage:
Vertical loads not in hinges → low hinge wear, long life cycle

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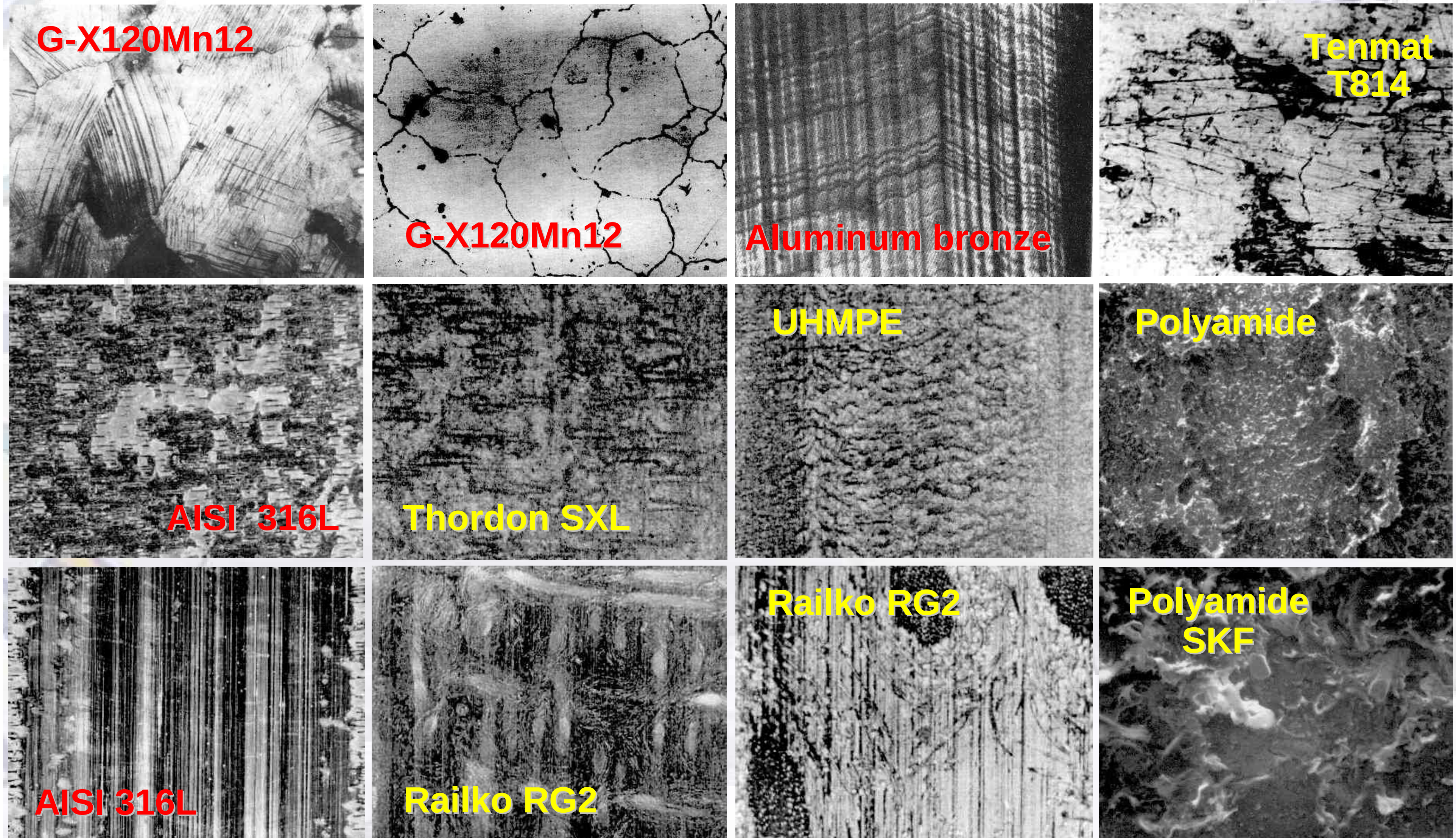
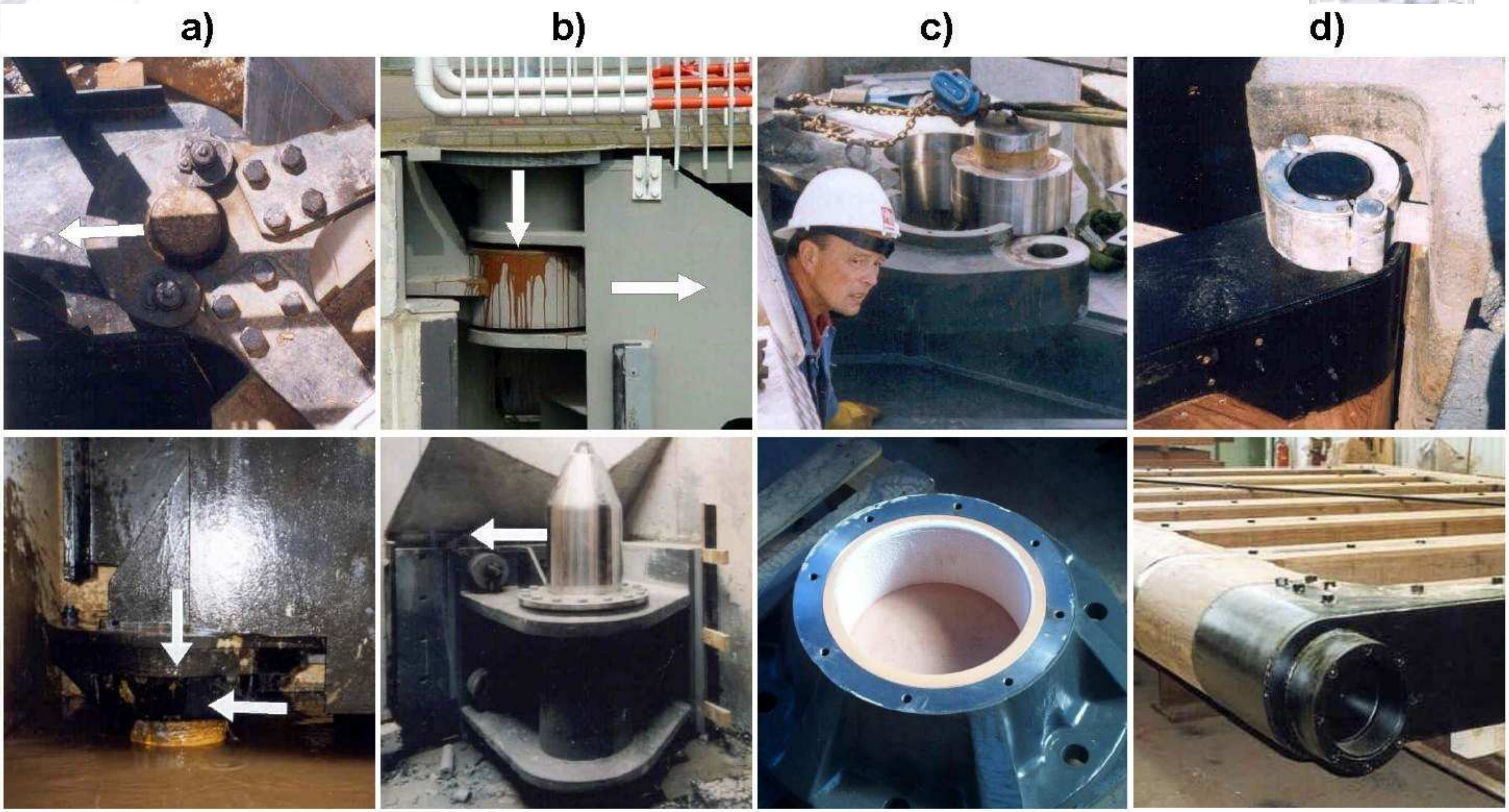
MATERIAL SOLUTIONS



MATERIAL SOLUTIONS



2nd Lock Lith the Meuse	Orange Locks Amsterdam	Naviduct Enkhuizen	Wilhelmina Canal Tilburg

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NEW PIANC WGs – Are you interested ?

1. - LOAD AND STRENGTH ASSESSMENT

Load and strength are linked when structural engineers design lock gates and valves, first at the early design stage (to assess weight and cost) and later at the final design stage (construction drawings).

Nowadays most difficult issues issues concern :

➔ Seismic effect on lock gate

- additional loads (external and internal)

- behavior during gate motion

-

➔ Ship collision on lock gates

The challenge for the next years is to identify relevant and cost/effective specifications and requirements.

NEW PIANC WGs – Are you interested ?

2- LOCK MOORING AND SHIP BEHAVIOR IN LOCKS

«Mooring requirements for ships during filling and emptying and ship behavior during lock entrance/exit»

Main targets are:

- Definition of the requirements, to impose at the design stage, on mooring forces, ship motion in lock chamber, etc.

- State of art to assess the forces acting on ships (in lock), the ship motion and the mooring forces (physical modelling, numerical modelling and field measurement).

- The effects of density current must be investigated,

- Ship behavior during entrance and exit of the locks (approach maneuvering), and particularly in case of density currents (salt water intrusion).

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