Paper 9, part A - LOCK GATES - INNOVATIVE CONCEPTS

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ABSTRACT: This paper introduces some new innovative concepts identifies by the INCOM WG29 and reported in the PIANC report 106 "Innovations in Navigation Lock Design", 2009.

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.

2. MECHANİCAL PARTS: SEALS, BEARİNGS, HYDRAULİC CYLİNDERS, OPERATİNG EOUİPMENT

The main points about the mechanical parts are given in the Table 1.

The key points to consider during the design of mechanical parts is the **Gate operation**. Operating machinery is critical locks equipment because this equipment is subjected to intensive operation. Lock availability depend mainly on the machinery performance and reliability.

For navigation locks, there are typically four types of drives, which are used to develop operating forces:

- Electric-mechanical drives,
- Oil hydraulic drives
- Electromechanical actuators, using a capsulated threaded pin. Due to the head sealing of the mitre gate the drive is always dry (Fig. 1)
- Oil hydraulic compact drives

The last two types of drives relate to recent developments, which were mainly designed to reduce maintenance.

Table 1 - Main Mechanical Parts

	echanicai Parts
FUNCTIONS	ELEMENTS
Gate operation and power	- actuators
supply (transmission of a force	- drives (cylinders,
to the mobile structure)	electro-mechanical
to the mosne structure)	drives, etc.)
	- motors
	- chain, cables
	- Chain, Cabies
Guiding (rotation,	- rails
•	- **
translation)	- wheels and rollers
	- pivot, bearing
Bearing and contacts	
(sliding, rolling or static)	
(transmission of forces to the	 pivot , bearing
foundation of the lock)	 fixed elements for
	guiding or sealing
Sealing	- seals
_	
Maintenance	- accessibility
	- capacity to remove
	and change elements
(transmission of forces to the foundation of the lock) Sealing	 pivot , bearing fixed elements for guiding or sealing seals accessibility capacity to remove

3. NEW İNNOVATİVE GATE CONCEPTS

3.1 Reverse Mitre Gate.

Recently innovative gate operating systems were designed to combine the link between the gate and the operating cylinder plus a retaining strut to resist the effects of a reverse head imposed by flood conditions. Such system is, in principle, suitable for limited water heads and rehabilitation works.

Nevertheless the progress performed in hydraulic cylinder reverse water heads of 2 and 3 m can be reached (for instance in the IJmuiden locks in the Netherlands). In these cases the cylinders work in compression (reversed head) or in tensile (standard head) – See Fig. 1.



Fig. 1: Reverse Mitre Gates (IJmuiden-NL)

3.2 Folded plate gates

It is now possible to use complex geometric folded plate for lock gate structures (Fig. 2). Therefore the advantages are:

- Some redundancy in the bearing capacity
- Simplified maintenance and inspection
- Well designed to avoid fatigue damage
- Favourable corrosion protection characteristics



Fig. 2 - Folded plate of a mitre gate at Uelzen II

3.3 Suspended Mitre gates

There is an innovative solution to the problem of gate hinge wear, so-called 'suspension gate', for mitre or single-leaf gate system (Figs 3 and 4). The gate leaves are suspended to a rope, chain or other torque-flexible member – anchored in the leaf

rotation axis and hooked to a small tower or console. Both the top and the bottom hinge carry only horizontal reactions in this way, which significantly decreases the wear and helps solving some fatigue related problems.

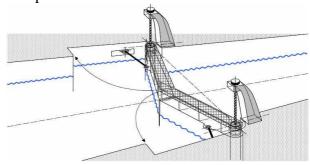


Fig. 3 - Suspended Mitre Gate



Fig. 4 -Mitre gates supported only at their top hinges

3.4 Rotary segment gates with horizontal axis

Rotary segment gates (Fig 5) can be used as a upper lock gate for a large water head if a separate filling systems exists. When filling the lock through the gate, a lift height of 8 m is the maximum lift which are currently planned in Germany.



Fig. 5 - Upper gate at lock Lisdorf during inspection (left) and during a test for flood discharge

3.5 Vertical-axis Sector Gates

Vertical-axis sector gates (Fig 6) are an efficient and economical solution where there is a requirement for a lock gate to accept a head difference in either direction. They can allow simple filling and emptying of the locks without provision of separate sluice gates or culverts.



Fig.6 - Vertical-axis sector gates

3.5 Composite lock gates

CETMEF (France) has studied a vertical lift arch gate made out of composite materials. Similarly the "Spieringsluis" in the Netherlands was designed with a high strength synthetic composite material to reduce the higher maintenance costs of wooden or steel gates. The average preventative maintenance duration with wood or steel gates is 15 to 25 years.

Main advantages of composite arch gates are:

- No corrosion:
- Good resistance to aging in damp environment;
- Finishing paint useless, thereby seriously reducing maintenance costs;
- Lightness, easing transportation and fitting of the gate;
- Lightness reducing the purchasing and maintenance costs of the machinery;
- Gate positioning on the river side of the lock heads, easing maintenance and reducing the risk of collision of the gate and/or machinery.

3.6 Self-propelled floating lock gates

Self-propelled floating lock gates may replace traditional wheel barrows gates. Such gate (Fig 7) is an alternative to the standard rolling gates (wheelbarrow) and hydrolift gates that are commonly used for large maritime locks. The idea is to use a floating gate that is self propelled to close/open the lock (as a transversally rolling gate does).

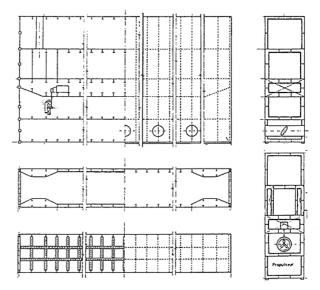


Fig.7 - Typical Cross Sections in a Self-Propelled Floating Lock Gate – 70 m long

3.7 Sliding gate – Hydrojet (Fig 8)

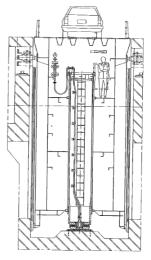


Fig. 8 - Hydrojet – Oranje lock (NL)

3.8 Rolling gates with integrated filling/emptying system

In Germany, an innovative gate system (Fig 9) combines the advantages of a lifting gate, where the gate body also forms the closure for filling and emptying the lock chamber, with those of a sliding gate.

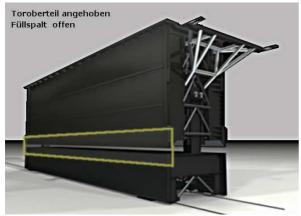


Fig. 9 - Kaiser lifting and sliding lock gate

4. GATE TİGHTNESS, LİNİNGS AND SEALS

→ The "come back" of sliding gates/valves

In the Netherland, Germany, Panama, etc. UHMPE (ultra-high molecular weight polyethylene) is nowadays considered a reliable teachnology and a very durable material to be used for sliding gate and lock filling and emptying valves.

It is a durable material a) long-service and b) environmentally favourable. It is chemically very stable and its mechanical properties are little sensitive to time, weather etc.

It is also recyclable (products: regenerate UHMPE down to low density PE e.g. for garden furniture) and at the very end it still has a high energy value when burned.

VALVES FOR FİLLİNG AND EMPTYİNG SYSTEM

There are four main types of valves (also called gates) that are currently used as filling and emptying regulation system:

- a) Radial gates (used as valves)
- b) Fixed wheel gates (fixed roller gates)
- c) Butterfly valves
- d) Sliding lift gates

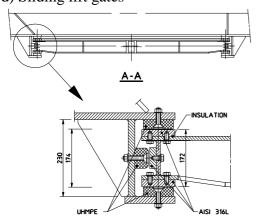


Fig. 10 -UHMPE sliding Gate sluice (Naviduct, NL)

The sliding lift gate is based on a high mechanical performance sliding material with a low friction coefficient. The material provides both guiding and sealing functions. It is placed on both sides of double-sealed gates and embedded parts depending on the mechanical design adopted. UHMWPE has the following characteristics:

- low friction coefficient (significantly less than 0.2);
- low wear index, which would mean the installation would not require any significant maintenance (wear < 4 mm in 35 years – working life);
- maximum stress = $2 \text{ N/mm}^2 < 6 \text{ N/mm}^2$.

UHMPE is nearly a standard solution for such contacts in the modern Dutch vertical lift gate sluices e.g. see as the valves of the Naviduct Enkhuizen (NL)-Fig 10..

6. CORROSION PREVENTION and CORROSION PROTECTION

In the last decade, the costs associated with the maintenance of infrastructure (bridges, locks, etc.) have increased dramatically due to the development of more stringent environmental regulations.

Durability and economic maintainability are both directly proportional to corrosion preventive measures taken.

Corrosion prevention of metal, which should be built into the design, must not be confused with **corrosion protection**, which is regarded as a secondary item to be apply to the structures at the building stage.

7. GATE EQUIPMENT

As example of new technologies, there is the magnetic automatic innovative mooring systems are now available (Fig. 11).



Fig. 11 - Magnetic Mooring System at KaiserLock Germany (*Cavotec Ltd*)

PIANC - InCom Work Group 29



Lock Gate and Ship Impact

- Report n°106, 2009 -

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Lock Gate and Ship Impact



Part A: LOCK GATES – INNOVATIVE CONCEPTS
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Part B: SHIP IMPACT
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LOCK GATES – INNOVATIVE CONCEPTS



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.

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LOCK GATES – INNOVATIVE CONCEPTS



2. - MECHANICAL PARTS: SEALS, BEARINGS, HYDRAULIC CYLINDERS, OPERATING EQUIPMENT

The main points about the mechanical parts (see Table 1 in Report):

- The key points to consider during the design of mechanical parts is the Gate Operation.
- Operating machinery is critical locks equipment because this equipment is subjected to intensive operation.
- Lock availability depend mainly on the machinery performance and reliability.



LOCK GATES – INNOVATIVE CONCEPTS



Electromechanical actuators, using a capsulated threaded pin (Germany)

Mitre gate at Uelzen II

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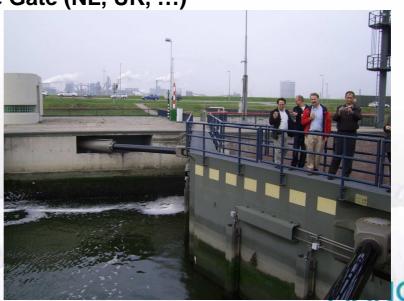
3- NEW INNOVATIVE GATE CONCEPTS



a- Folded Plate for gates (Germany) - see previous page

b-Reversed Mitre Gate (NL, UK, ...)

Reverse
Mitre Gate
(IJmuiden-NL)

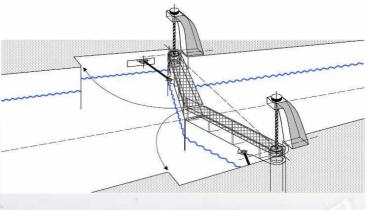


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c- Suspended Mitre Gates (NL)





Suspended Mitre Gate

Mitre gates supported only at their top hinges

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NEW INNOVATIVE GATE CONCEPTS



d- Rotary Segment Lock Gate (horizontal axis) - Germany





Lisdorf Lock – Flood discharge through the lock

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e- Vertical-axis Sector Gates (Germany, Finland, Japan, ...)



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NEW INNOVATIVE GATE CONCEPTS



f) COMPOSITE LOCK GATES

CETMEF (France) → vertical lift arch gate with composite materials.

RWS - the "Spieringsluis" → high strength synthetic composite material to reduce the higher maintenance costs of wooden or steel gates.

Main advantages of composite arch gates are:

- No corrosion;
- Good resistance to aging in damp environment;
- Finishing paint useless, → reducing maintenance costs:
- Lightness, easing transportation and fitting of the gate;
- Lightness reducing purchasing and maintenance of C machinery:



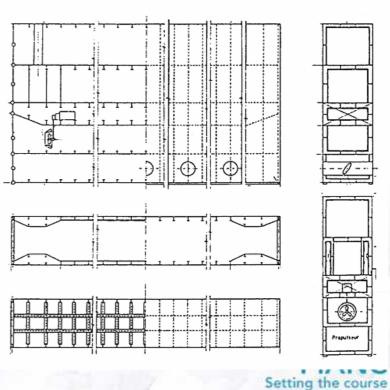
g) Self-propelled floating lock gates

Maritime locks

→ Cost savings

ANAST-ULG

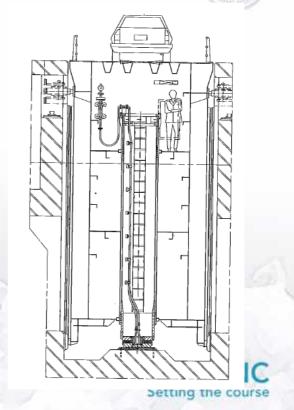
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NEW INNOVATIVE GATE CONCEPTS

h- Sliding gate – Hydrojet (NL)

Hydrojet
Oranje lock (NL)





i) Rolling gates with integrated filling/emptying system



LOCK GATES – INNOVATIVE CONCEPTS



- 4. GATE TIGHTNESS, LININGS and SEALS
 - → The "come back" of sliding gates/valves

In the Netherland, Germany, Panama, etc.

UHMPE (ultra-high molecular weight polyethylene) is nowadays considered a reliable teachnology and a very durable material to be used for sliding gate and lock filling and emptying valves.



LOCK GATES – INNOVATIVE CONCEPTS

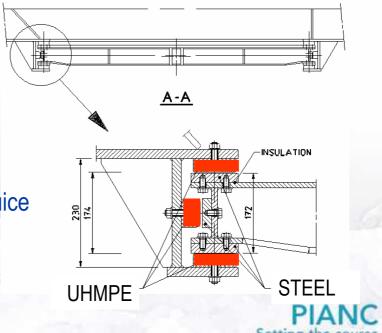


5. - VALVES for FILLING/EMPTYING SYSTEM



UHMPE sliding Gate sluice (Naviduct, NL)

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LOCK GATES – INNOVATIVE CONCEPTS



5. - VALVES for FILLING/EMPTYING SYSTEM

→ USE of UHMPE (ultra-high molecular weight polyethylene)

Sliding lift gate with UHMPE is based on a high mechanical performance sliding material with a low friction coefficient.

The material provides both guiding and sealing functions.

UHMWPE has the following characteristics:

- low friction coefficient (< 0.2);
- low wear index (wear < 4 mm in 35 years working life);
- maximum stress (6 N/mm²)

UHMPE is nearly a standard solution for such contacts in the modern Dutch vertical lift gate sluices e.g. see as the valves of the Naviduct Enkhuizen (NL)

LOCK GATES – INNOVATIVE CONCEPTS



- a) In the last decade, costs associated with maintenance of infrastructure have increased dramatically due to the development of more stringent environmental regulations.
- b) **Durability and economic maintainability** are both directly proportional to corrosion preventive measures taken.
- c) Corrosion prevention of metal, which should be considered at the design stage, must not be confused with corrosion protection, which is regarded as an other item to consider but at the building stage.

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LOCK GATES – INNOVATIVE CONCEPTS



7. – GATE EQUIPEMENT

Magnetic automatic innovative mooring systems



Magnetic Mooring System at KaiserLock (Cavotec Ltd)

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Part b: Ship Impact

- Report n°106, 2009 -

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WG29 – LOCK GATE AND SHIP IMPACT

Plan

- 1. Introduction
- 2. Ship impact analysis: state of art
 - a) Empirical approach
 - b) Analytical-Rational approach
 - c) FEM, quasi-static analysis
 - d) FEM, dynamic analysis
- 3. One example: "Seine-Escaut Est"
- 4. Conclusion

Introduction

New project: recommendations?

1. Define a "vessel impact" design criterion (ship weight and speed)

Panama canal:

- 160,000 t
- 0.5 m/s
- With no loss of water tightness and the global resistance
 => consistent with the project
- 2. Protective measures VS gate designed to sustain ship impact

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WG29 – LOCK GATE AND SHIP IMPACT

Introduction

Gate = ship stopping device
Structure must combine sufficient <u>flexibility</u> with sufficient <u>load</u>
bearing capacity to successfully <u>absorb the kinetic energy</u>

Analysis to perform to design the gate structure?

- a) Empirical approach
- b) Analytical-Rational approach
- c) FEM, quasi-static analysis
- d) FEM, dynamic analysis



State of art: empirical approach

- Methods based on empirical data and practice experience
- Very simple way to evaluate an order of magnitude
- Use it as a rule of thumb
 - → more detailed analysis must be performed

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State of art: analytical approach

Analytical models (Le Sourne)

Hypothesis – Approximations:

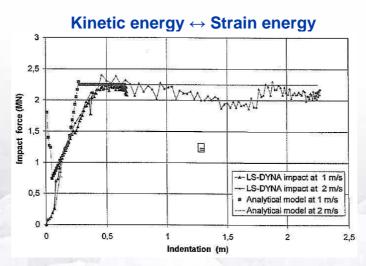
- Analytical model → simplifications
- Totality of the energy dissipated by the gate
- No change in the contact
- No dynamic effect (vibrations, ...)

Numerical studies have validated these assumptions for simple cases

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State of art: analytical approach

The impact force – indentation relationship can be obtained



Impact forces comparison (Le Sourne) - Dynamic analysis VS analytical model

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FEM, quasi-static analysis

Finite Elements Methods Neglect the dynamic effects \rightarrow quasi-static analysis

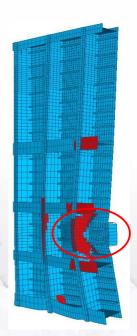
One possibility:

Simple model of the bow of the ship

→ ex: perfectly stiff rectangular element

No evolution of the contact between the bow and the gate

Load Fimpact on the bow increased until equalization of the energies

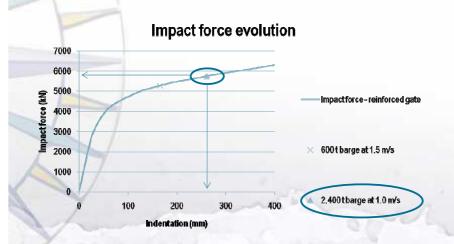


Lock gate simply supported on three sides

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FEM, quasi-static analysis





Indentation 26 cm and impact force 5,75 MN (energy: 1,20 MJ)

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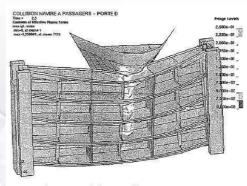
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FEM, dynamic analysis

LS-DYNA

- Possibility of modeling the deformable bow of the ship
- ⇒ Giving an initial position and speed, the contact can be considered
- Dynamic effects taken into account

... But highly time-consuming



Passenger ship impact: effective plastic strains at t=2,3 sec.

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Which analysis perform?

Empirical: gives an order of magnitude of the impact strength

<u>Analytical</u>: very effective and time-saver for gate structure with plane geometry but must be correctly applied (assumptions to validate)

<u>FEM, quasi-static</u>: gives good results when a dynamic analysis can't be performed

FEM, dynamic: accurate but time consuming. Using it for few cases can offer reference results to validate assumptions made in other methods

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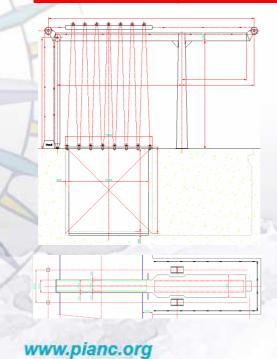
One example: "Seine-Escaut Est"

Lock gate designed for the "Seine-Escaut Est project" in Belgium



Downstream lock gates: length 13.7 m; height 13.6 m Gates suspended and manoeuvred by lateral movement

One example: "Seine-Escaut Est"



First, optimization of the structure considering hydrostatic load cases

→ Elastic design

Total weight: 51.4 t

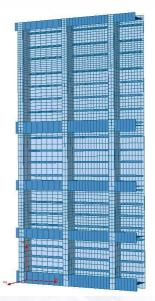
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One example: "Seine-Escaut Est"

Then, analysis of the ship impact

It was decided to perform a FEM quasi-static analysis using the *FINELG* software



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FEM, quasi-static analysis – example

Analysis of 3 scenarios

- 1. Upstream water level (U.W.L.) without any hydrostatic load
- 2. Upstream water level with hydrostatic service load (7.50 m)
- 3. Downstream water level (D.W.L.) without any hydrostatic load



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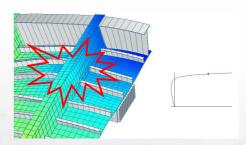
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FEM, quasi-static analysis – example

U.W.L. with the initially optimized structure

Low thickness of the frames and girders (slenderness ratio: Hugues' criteria for T-elements)

Impact force evolution 3000.00 2500.00 1500.00 0.00 0 20 40 60 80 100



⇒ Buckling of the central frame

indentation (mm)

- ⇒ Fragile behavior sudden collapse low capacity for energy dissipation
- ⇒ Choice of reinforcing the structure

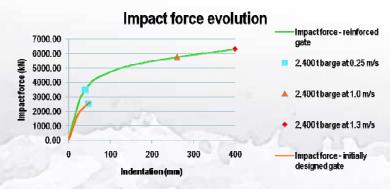


FEM, quasi-static analysis – example

Reinforcing the structure

Aim: avoid instability phenomenon – increase ductility

Dimensions of frames and girders increased (slenderness ratio: EN class 1) Total weight: $51.4 t \rightarrow 68.7 t (+34\%)$



By using class-1 sections for frames and girders, we improve the gate behaviour in case of ship impact

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FEM, quasi-static analysis – example

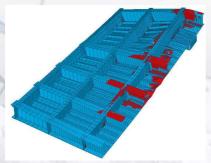
Reinforced gate

Ductile behaviour – very significant capacity for energy dissipation

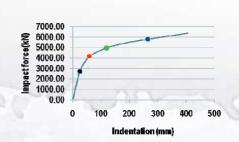
Initially optimized structure: 0,08 MJ

Reinforced structure: 2 MJ (i.e. a 2,400 t barge at 1.3 m/s)

Global plastic failure mechanism



Yielding at the collapse stage (amplified x6)

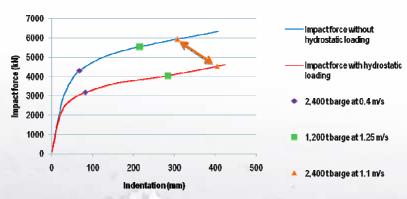


Apparition of successive plastic hinges in the girders

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FEM, quasi-static analysis - example

U.W.L., taking into account the hydrostatic loads



The global behaviour of the gate is identical but the structure is more deformable because previously submitted to a stress field

Neglecting the hydrostatic load leads to underestimate the deformation and the yielding of the structure − but overestimate the impact force

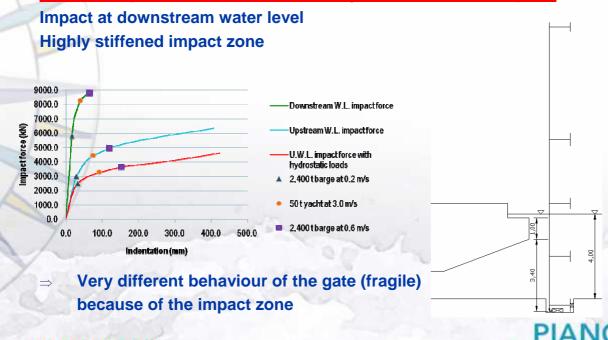
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FEM, quasi-static analysis – example

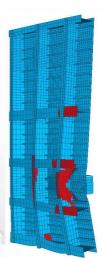


FEM, quasi-static analysis – example

Strain concentration in the impact zone leads to a fragile, sudden collapse

Transverse stiffness << Longitudinal stiffness

- ⇒ No propagation of yielding
- No global plastic failure mechanism
- ⇒ Collapse for a small indentation and low energy dissipation (0,5 MJ)



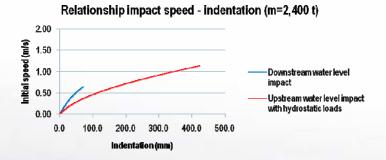
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FEM, quasi-static analysis – example

Results



Impact of a 1,200 t barge at 0.8 m/s (384 kJ)	U.W.L. without hydrostatic loads	hydrostatic	D.W.L.
Impact force	4,845 kN	3,550 kN	8,706 kN
Indentation (only due to the impact)	11.1 cm	13.9 cm	5.9 cm
hinges in frames and	2 girders	3 girders	1 frame



FEM, quasi-static analysis – example

Conclusion:

- 1. Aim: to design a gate able to resist the ship impact by itself
- 2. To dissipate energy, it needs ductility (avoid instability)
- 3. Ductility of the elements can be achieved by using EN class-1 cross sections (increasing dimensions of frames and girders)
- 4. Ductility of the gate requires a good propagation of yielding, which can be achieved by a good design of the stiffness ratios in the potential impact zones

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FEM, quasi-static analysis – example

- Lock gates: <u>elastic</u> design considering hydrostatic loading
- Impact analysis: increase the dimensions of the frames and girders
- Recommendation: new constraint in the optimization software to obtain optimized solutions considering impact strength
- Then, comparison (cost): reinforced solution VS elastic optimum solution coupled with protective measures against ship impact





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Thank you

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