



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 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.

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



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

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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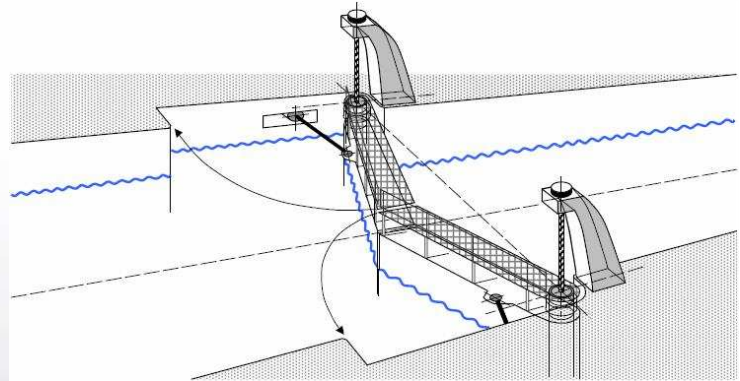


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NEW INNOVATIVE GATE CONCEPTS



c- Suspended Mitre Gates (NL)



Suspended Mitre Gate

Mitre gates supported only at their top hinges

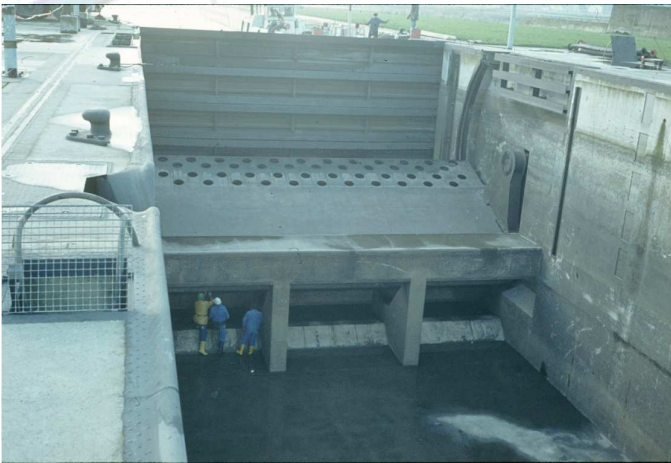
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NEW INNOVATIVE GATE CONCEPTS



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 machinery;

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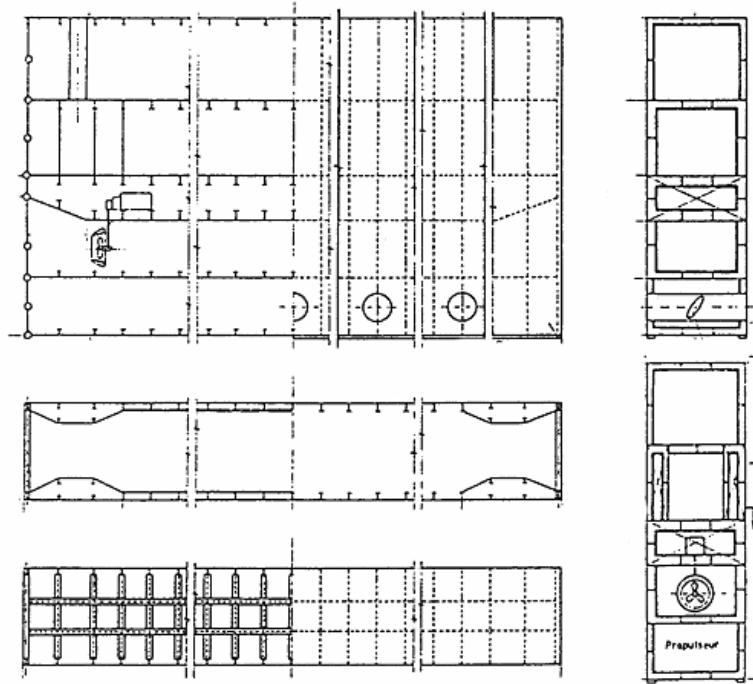
NEW INNOVATIVE GATE CONCEPTS



g) Self-propelled floating lock gates

Maritime locks
→ Cost savings

ANAST -ULG



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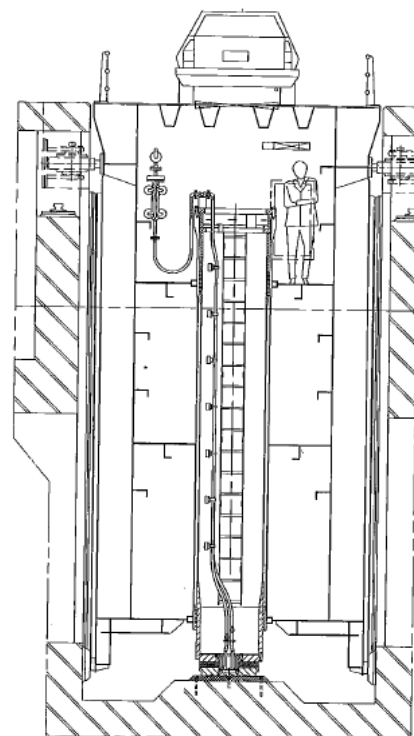
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NEW INNOVATIVE GATE CONCEPTS



h- Sliding gate – Hydrojet (NL)

Hydrojet
Oranje lock (NL)



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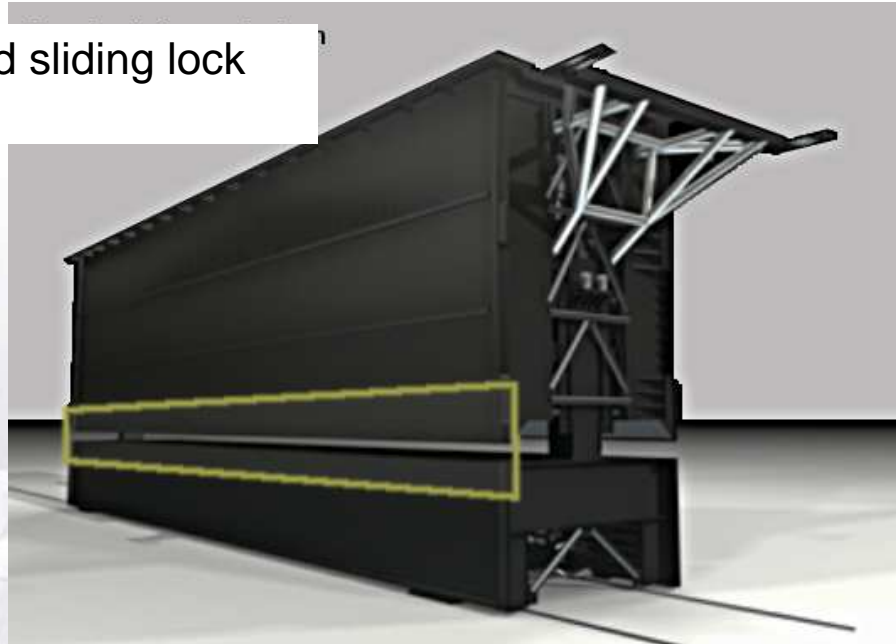
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NEW INNOVATIVE GATE CONCEPTS



i) Rolling gates with integrated filling/emptying system

Kaiser lifting and sliding lock gate



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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 technology and a very durable material to be used for sliding gate and lock filling and emptying valves.

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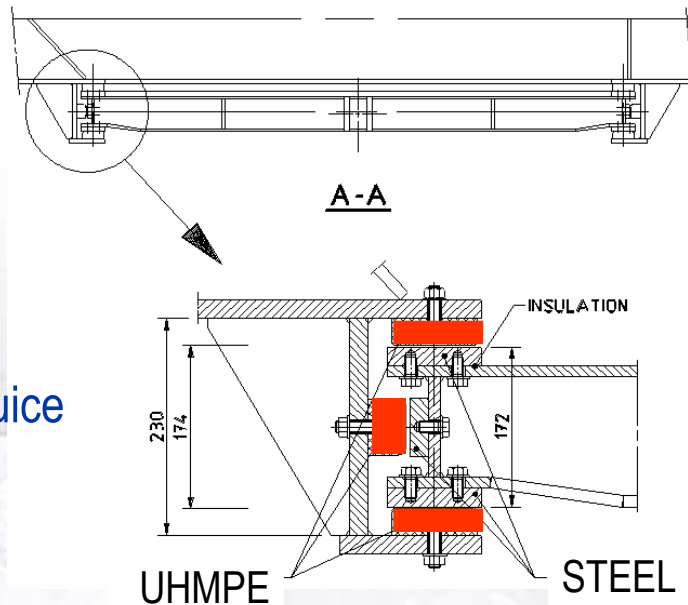
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5. – VALVES for FILLING/EMPTYING SYSTEM

Use of UHMPE

UHMPE sliding Gate sluice
(Naviduct, NL)



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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)

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6. – CORROSION : PREVENTION and PROTECTION

- 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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7. – GATE EQUIPEMENT

Magnetic automatic innovative mooring systems



Magnetic Mooring System at KaiserLock (Cavotec Ltd)

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Part b: **Ship Impact**

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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

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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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Introduction

3. Gate = ship stopping device
Structure must combine sufficient flexibility with sufficient load bearing capacity to successfully absorb the kinetic energy

Analysis to perform to design the gate structure?

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

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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, ...)

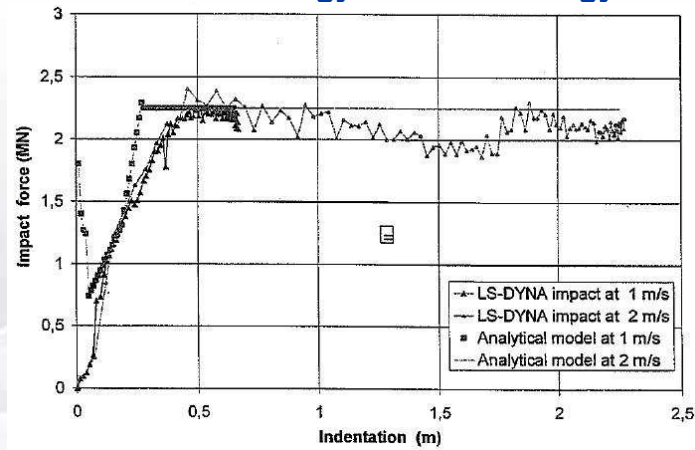
Numerical studies have validated these assumptions for simple cases

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State of art: analytical approach

The impact force – indentation relationship can be obtained

Kinetic energy \leftrightarrow Strain energy



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

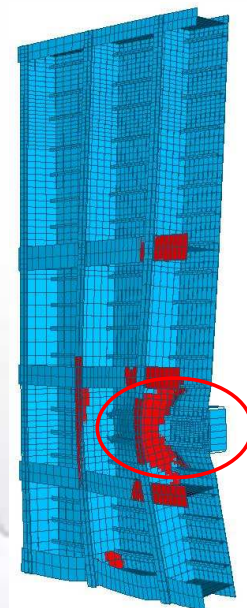
One possibility:

Simple model of the bow of the ship

\rightarrow ex: perfectly stiff rectangular element

No evolution of the contact
between the bow and the gate

Load F_{impact} on the bow increased
until equalization of the energies



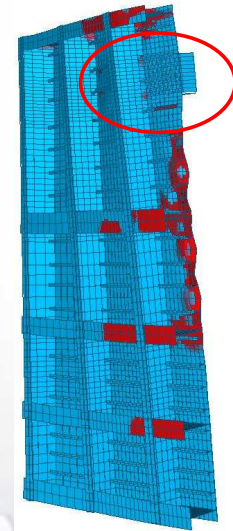
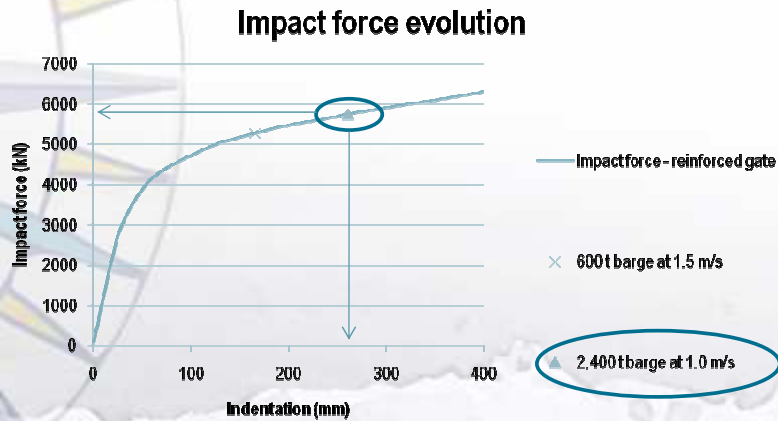
Lock gate simply supported on three sides

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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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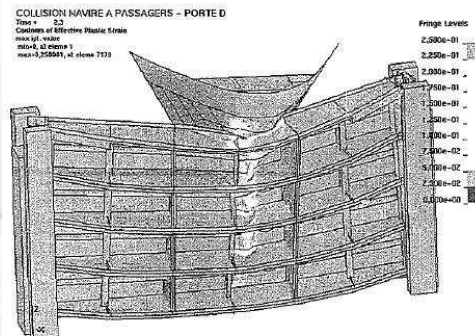
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FEM, dynamic analysis

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

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

FEM, quasi-static: 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



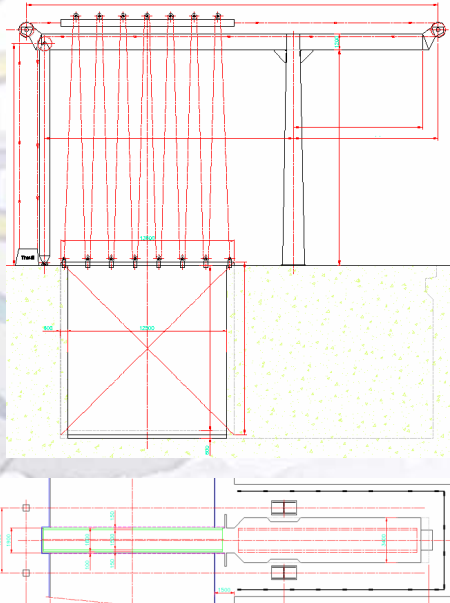
Downstream lock gates: length 13.7 m ; height 13.6 m

Gates suspended and manoeuvred by lateral movement

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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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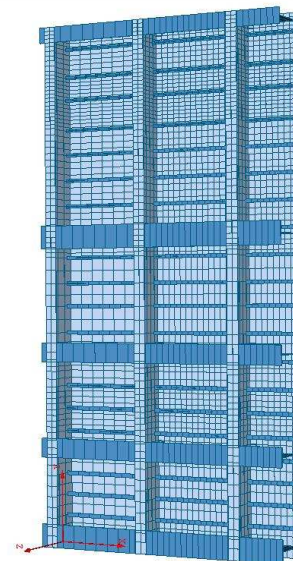
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One example: “Seine-Escaut Est”

Then, analysis of the ship impact

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



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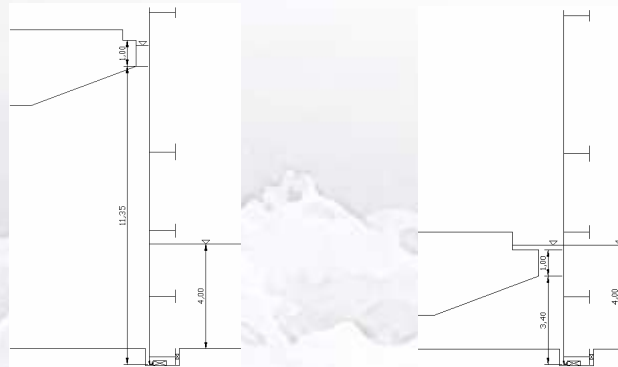
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FEM, quasi-static analysis – example

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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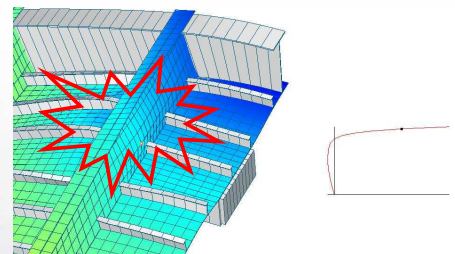
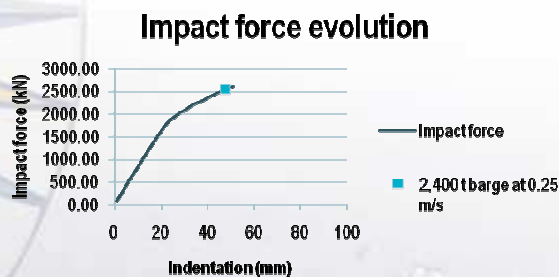
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FEM, quasi-static analysis – example

U.W.L. with the initially optimized structure

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



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

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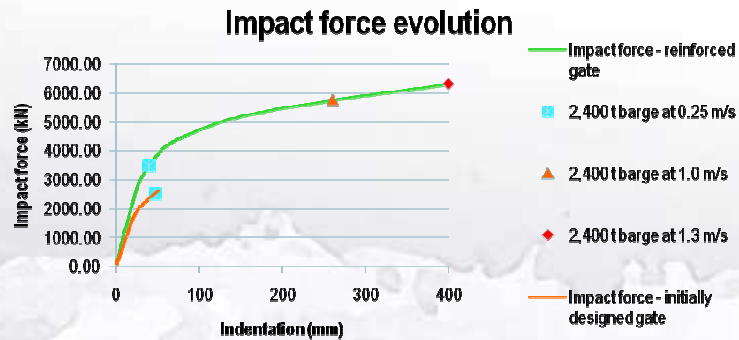
FEM, quasi-static analysis – example

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 → 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

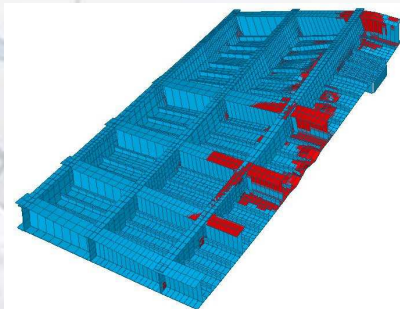
Reinforced gate

Ductile behaviour – very significant capacity for energy dissipation

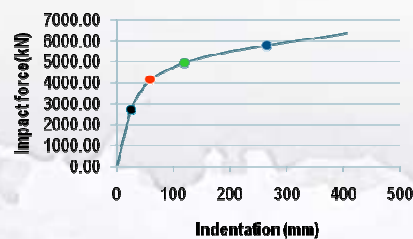
Initially optimized structure: 0,08 MJ

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

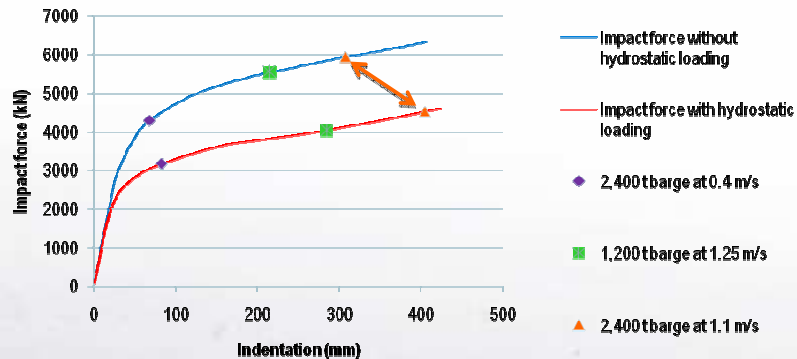
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FEM, quasi-static analysis – example

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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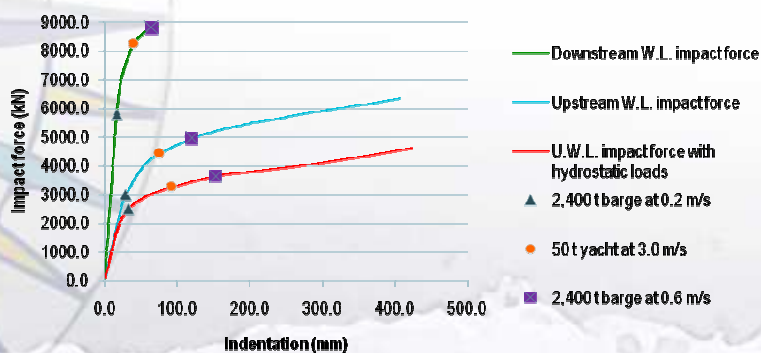
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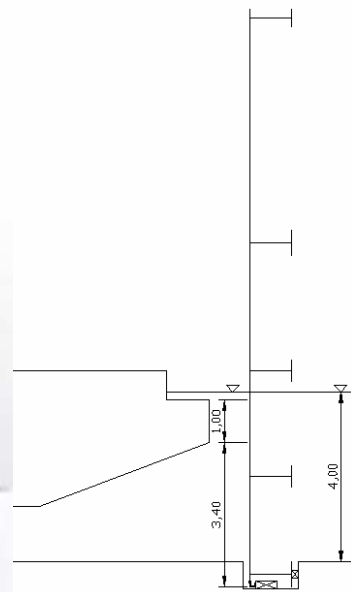
FEM, quasi-static analysis – example

Impact at downstream water level

Highly stiffened impact zone



⇒ Very different behaviour of the gate (fragile) because of the impact zone



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FEM, quasi-static analysis – example

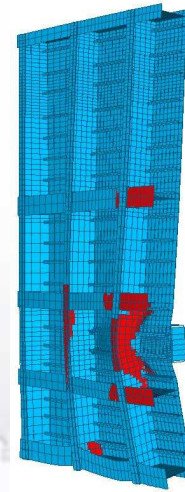
Strain concentration in the impact zone leads to a fragile, sudden collapse

Transverse stiffness \ll Longitudinal stiffness

⇒ No propagation of yielding

⇒ No global plastic failure mechanism

⇒ Collapse for a small indentation and low energy dissipation (0,5 MJ)

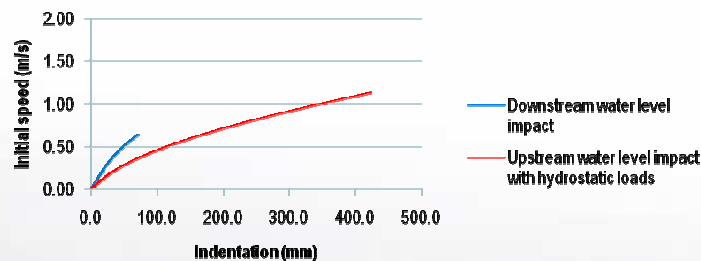


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FEM, quasi-static analysis – example

Results

Relationship Impact speed - Indentation (m=2,400 t)



Impact of a 1,200 t barge at 0.8 m/s (384 kJ)	U.W.L. without hydrostatic loads	U.W.L. with hydrostatic loads	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
Number of plastic hinges in frames and girders	2 girders	3 girders	1 frame

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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: elastic 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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References

- EUROCODE 3 – Design and construction of steel structures – Part 1.1: General rules and rules for buildings, EN 1993-1-1, CEN, Brussels, 2005
- HUGUES O.F., “Ship structural design: A rationally-based, computer-aided optimization approach”, Edited by the SNAME, New Jersey, 566p.
- GERNAY T., “Aménagement de la voie navigable “Seine-Escaut Est”: conception et calcul des portes aval des écluses de Marchienne-au-Pont, Gosselies, Viesville et Obourg”, Master thesis, University of Liège, 2009
- LE SOURNE H., RODET J.-C., CLANET C., “Crashworthiness analysis of a plane lock gate impacted by different river ships”, PIANC, 2003
- LE SOURNE H., RODET J.-C., CLANET C.: “Crashworthiness analysis of a lock gate impacted by two river ships”, Int. Journal of Crashworthiness, 2004
- PIANC report n°106 – 2009
- RIGO P., “Least Cost Optimum Design of Stiffened Hydraulic and Floating Structures”, PIANC Bulletin, n°101, April 1999, pp33-45
- RIGO P.: “L’optimisation des structures navales – minimisation du coût de construction de la coque métallique”, Institut pour la Promotion des Sciences de l’Ingénieur (IPSI), *Forum en Analyse de Structures : L’optimisation : des Techniques Eprouvées ?*, Vol. XXVI-1, Paris, March 2002, 44p.
- de VILLE de GOYET V., “FINELg, an advanced analysis and research program”, 1994 annual Task Group, Technical session, *In-Structural Stability Research Council (SSRC) – Link between research and practice, 50th Anniversary conference, Lehigh University, Bethlehem, Pennsylvania (USA), June 1994*

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