Global Overview of Navigable Storm Surge Barriers from a Dutch Perspective

ASCE Met Section Infrastructure Group Seminar 2009

Against the Deluge: Storm Surge Barriers to protect New York City
New York, March 30 and 31, 2009

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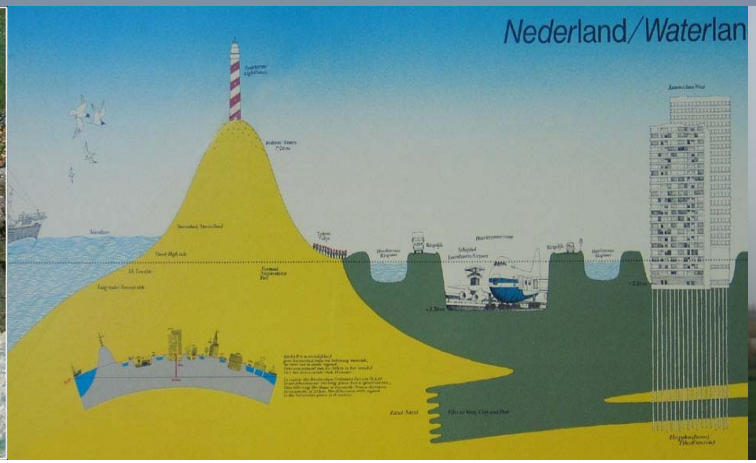

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Introduction

- Netherlands: centuries of protection against floods
- Dutch Delta Plan, water boards, dikes, levees and barriers
- Rotterdam: City of Water, world Port, flood issue comparable to NYC
- ARCADIS: Infrastructure, Environment, Buildings, Water

- Katrina: wake up call
- USACE New Orleans: IHNC Flood Gates Conceptual study
- Hurricane Protection systems approach including barriers
- Global overview of suitable gate types



Functions of a storm surge barrier

Primary function is storm surge protection

- Passage of ships (width, navigational depth, clearance)
- Discharge of water (wet cross section)
- Discharge of ice (free water length)
- Tidal flow (submerged sill, wet cross section)
- Passage of fish (wet cross section, flow velocity)

- Connection between both landsides for traffic

Other relevant aspects:

- Maintainability
- Reliability
- Environmental impact
- Impact on landscape
- Impact on water systems
- Constructability

Requirements and functional demands (1)

- Wet cross section for tidal flow and river discharge
- Water overtopping or leaking past the barrier
- Risk of failure (structural and closure) minimized
- Meet environmental impact criteria
- Sufficient flow & navigation during construction
- Controllable at design flow & wave conditions
- Hydraulic -, wind, ice loads
- Suitable for the required water depth & reverse head
- Flow- or wave-induced vibrations & oscillations

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Requirements and functional demands (2)

- Siltation impacts on gate operation
- Ready for operation preparation time
- Translation waves & differential head (closure)
- Sensibility for wind loads
- Vulnerability to impact of heavy objects (barges)
- Vulnerability to vandalism (terrorism)
- Clearance height & width of span for required shipping
- Accessible for inspection & maintenance
- Choice of materials and techniques for minimum maintenance

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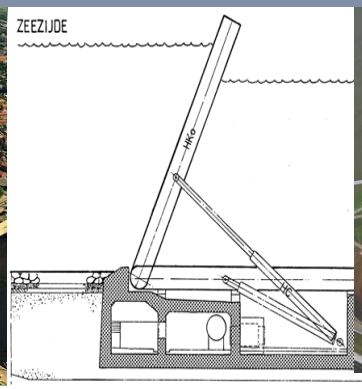
Types of navigable storm surge gates

1. Mitre gate: double-leaf gate
2. Vertical lifting gate
3. Flap gate
4. Horizontally moving or rotating gates (including sliding and floating sector gates)
5. Vertically rotating gates (including segment and radial gates) rotating in a vertical plane about a horizontal axis
6. Inflatable rubber dams mounted to the sill







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Mitre gates: Classic, often used in locks, canals

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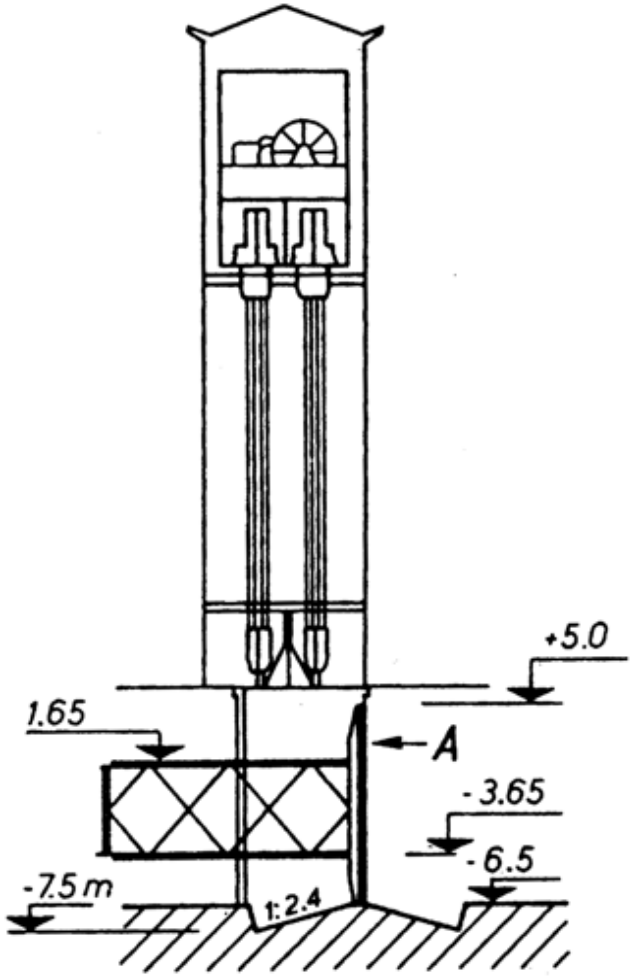
Mitre gates

favorable	unfavorable
Structural aspects, layout and operation	
• Unlimited clearance height for shipping • Little space required • Proven concept • Not subjected to wind	• Very limited gate span (up to 100 ft) • Little or no controlled operation under flow and waves
Hydraulic and hydrodynamic aspects	
• Horizontal closure • Discharge of excess water through gate	• Sensible to vibration as result of flowing water • Sensible to reverse head • Sensible to waves

Lifting gates: Krimpen Storm Surge Barrier, Netherlands



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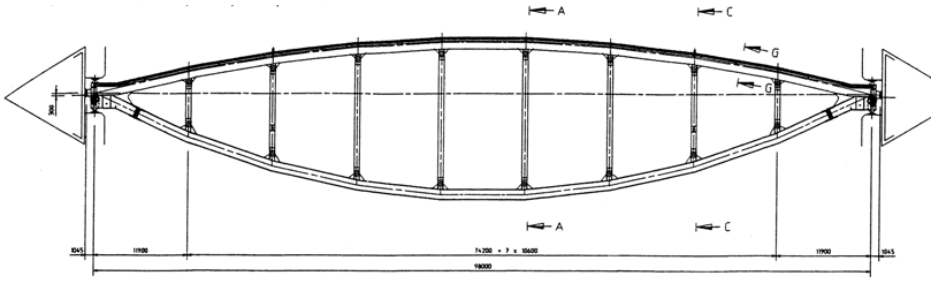
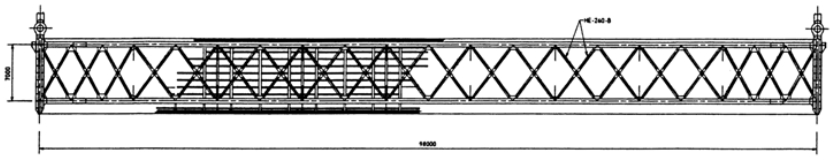
Lifting gates: Hartelkanaal Storm Surge Barrier, Netherlands





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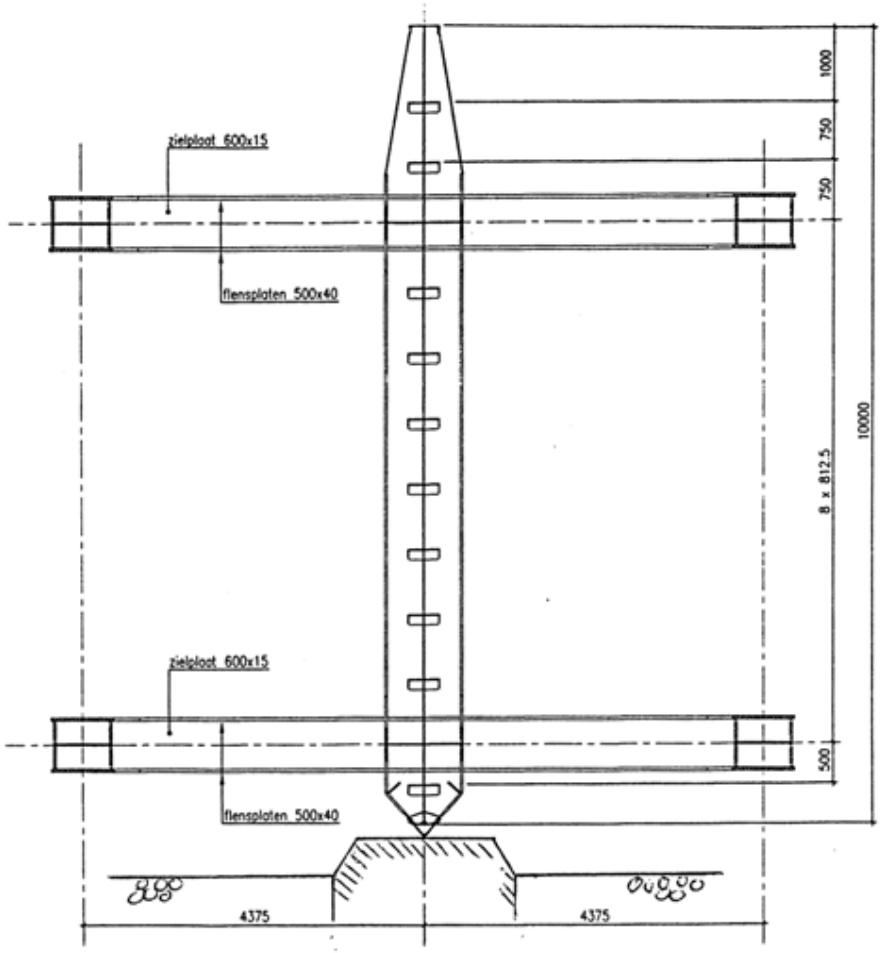
Lifting gates: Heusden Flood Barrier, Netherlands



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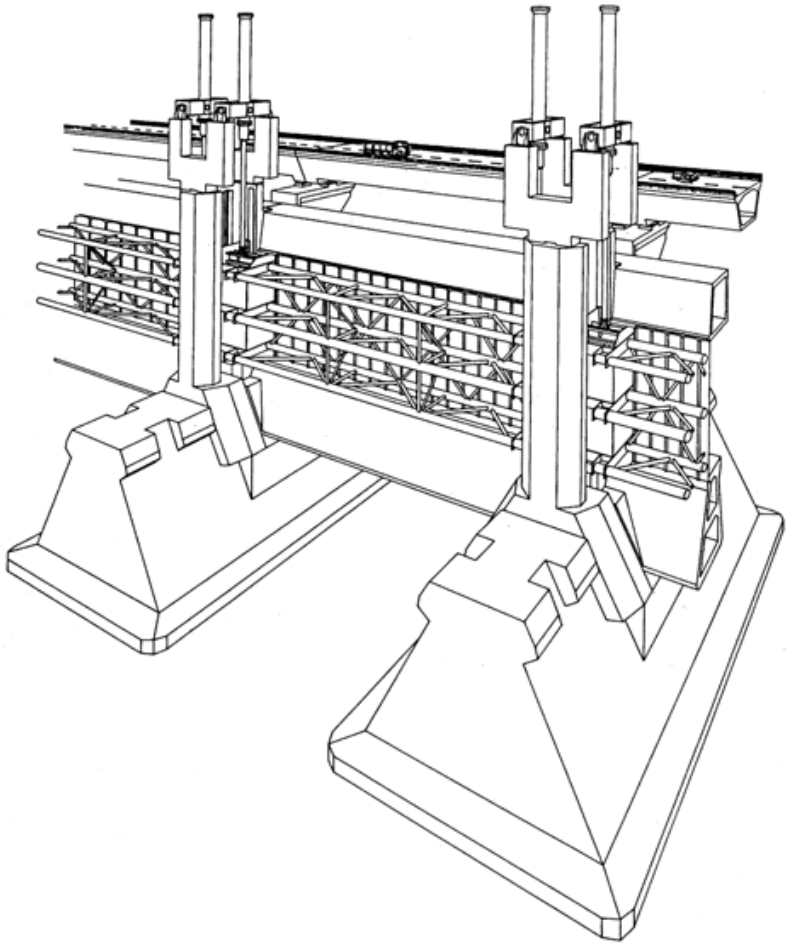
Lifting gates:
Oosterschelde Storm Surge Barrier, The Netherlands (1)



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Lifting gates:
Oosterschelde Storm Surge Barrier, The Netherlands (2)

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Lifting gates:
Oosterschelde Storm Surge Barrier, The Netherlands (3)

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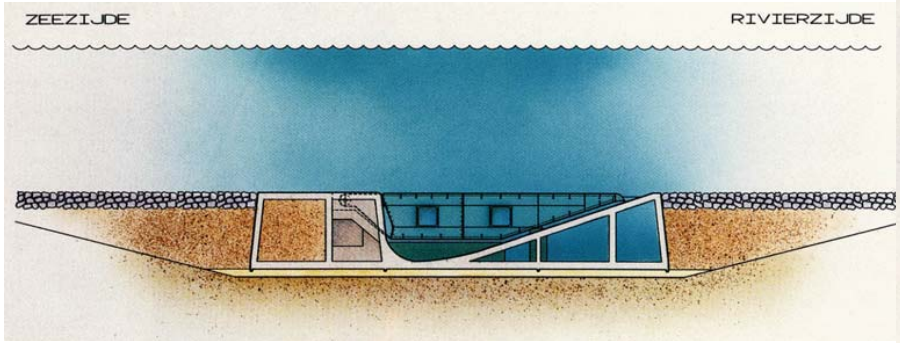
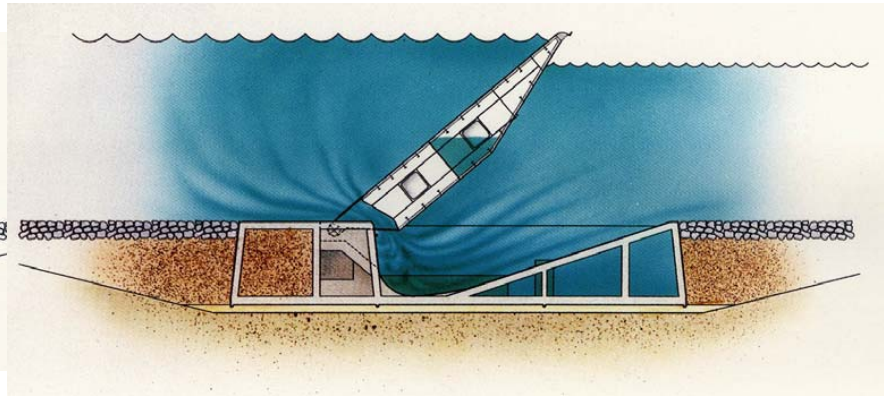
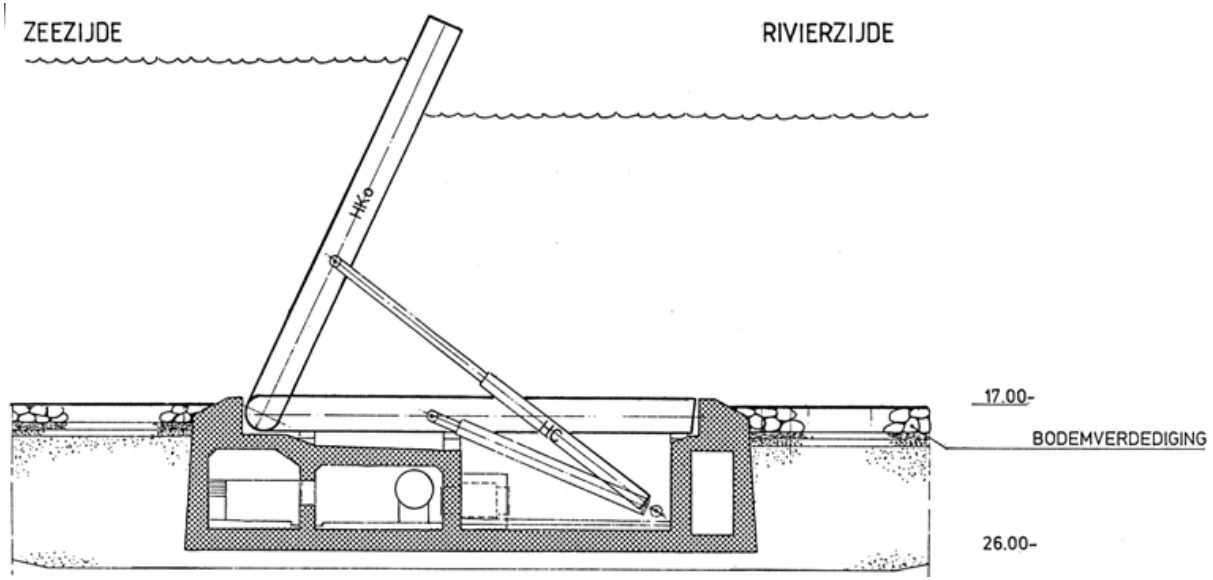
Vertical lifting gates

favorable	unfavorable
Structural aspects, layout and operation	
• Large gate span (up to 300 ft) • Little space required • Controlled operation under flow and wave • Raised gate accessible for maintenance • Proven concept	• Limited clearance height for shipping • Raised gate subject to wind load • Wheel gates weak spot, wearing • Smooth slide required ⇔ growth underwater
Hydraulic and hydrodynamic aspects	
• Vertical closure • Easy discharge of excess water • Overflow and reverse flow acceptable • Underside free of sill • Limited vertical flow forces & wave loads	• Sensitivity to vibrations • Subject to down-pull flow forces and wave loads

Flap gates: Maeslant Storm Surge Barrier, Netherlands (designs)







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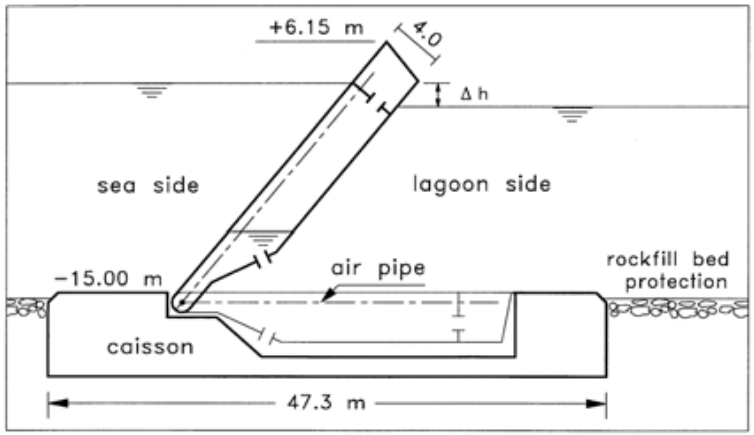
Flapgates: Venice Storm Surge Barrier, Italy



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Flap gates: Stamford Hurricane Barrier, Connecticut, USA

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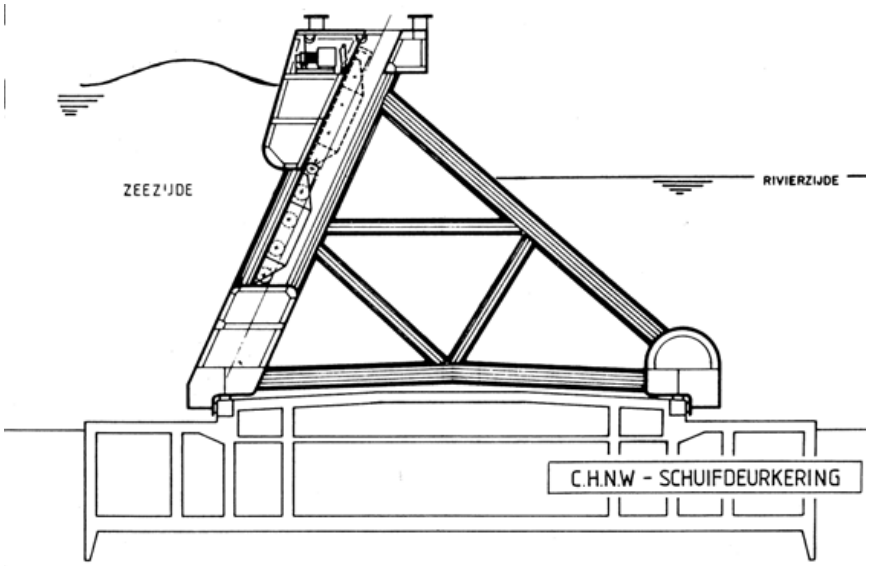
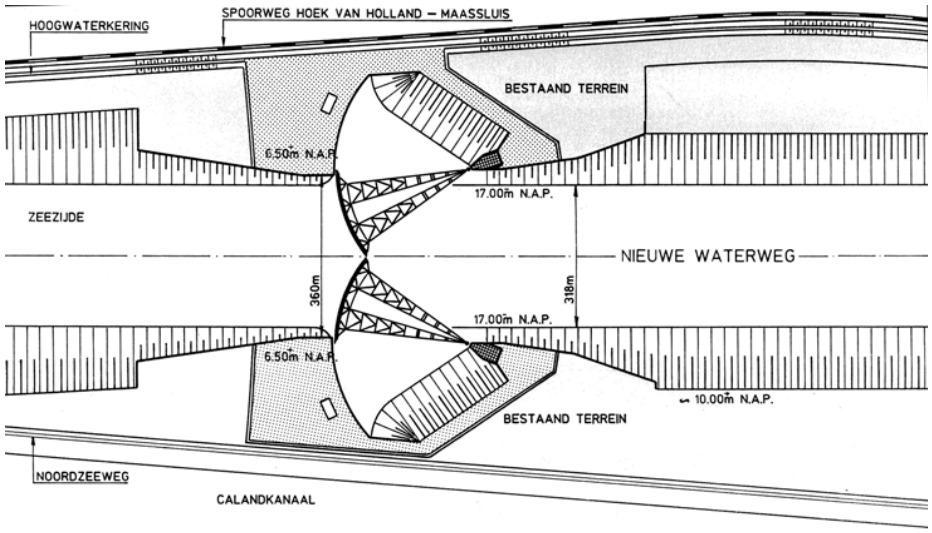
Flap gates

favorable	unfavorable
Structural aspects, layout and operation	
• No limitation of the span • No clearance height • Little space required • Suitable for deep waters • Controlled operation flow & wave • Not subjected to wind • Invisible when not in use	• Natural frequencies low, small stiffness, great mass • Pneumatic: not fully controlled • Hydraulic: concentration cylinders • Underwater: corrosion, growth • Hinges may wear out in sand • Maintenance difficult
Hydraulic and hydrodynamic aspects	
• No strong confinement of horizontal flow (gates alternately) • Vertical closure single flap • Excess water: through one flap or lowering the gate crest	• Sensitivity to vibrations

Horizontally moving:
Maeslant Storm Surge Barrier, Netherlands (design)





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Horizontally moving:
New Bedford Hurricane Barrier, Massachusetts, USA

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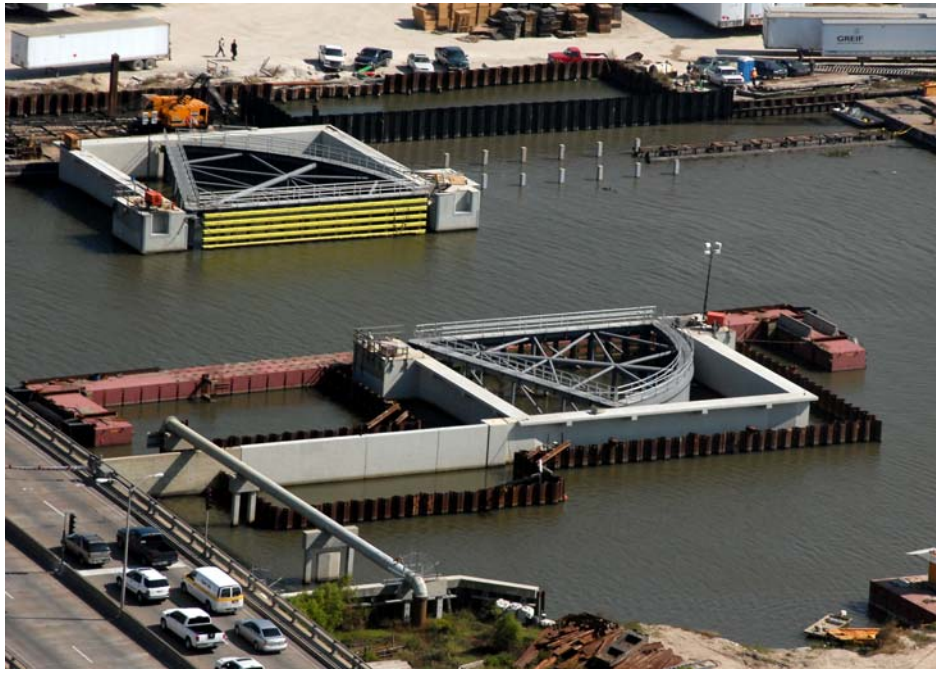
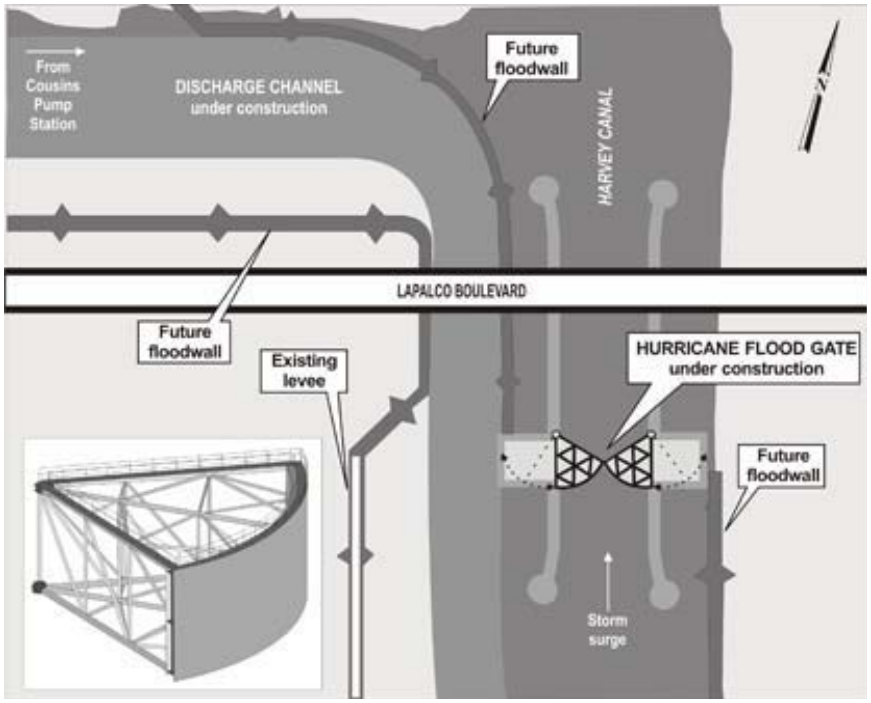
Horizontally moving:
Harvey Canal Flood Protection Barrier, New Orleans, USA





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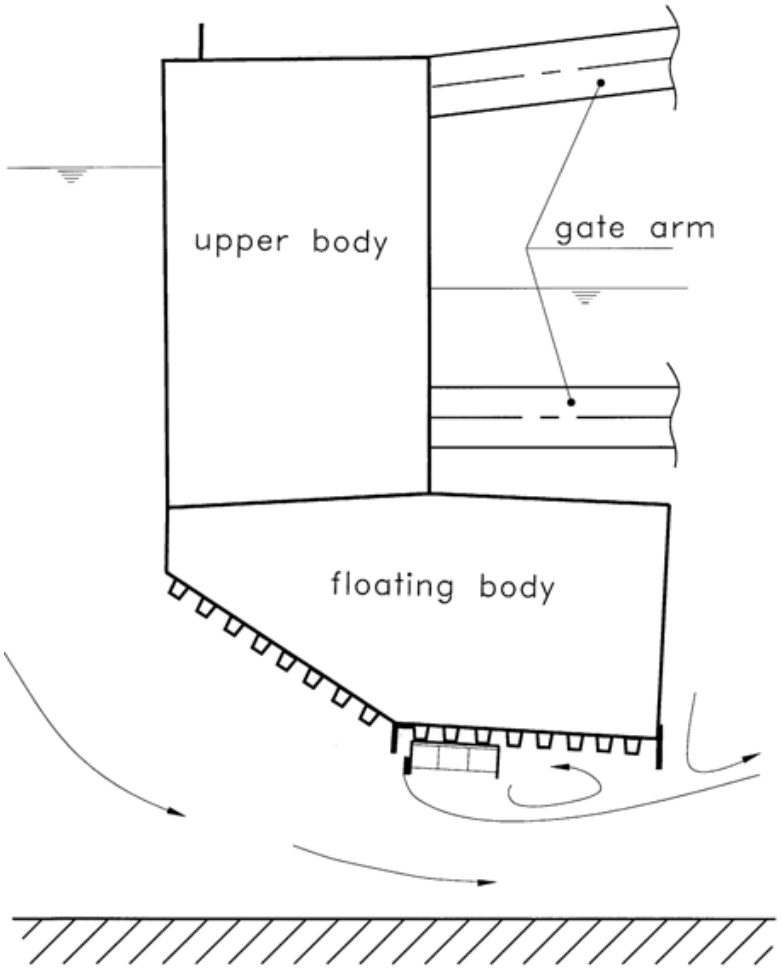
Horizontally moving or rotating gates

favorable	unfavorable
Structural aspects, layout and operation	
• Ultra Large span feasible • No clearance height limitation • Not subjected to wind • Suitable for deep waters • Free of sill, reduced load on sill • Stable structure, no load concentration • Dry docks: Maintenance, no collision	• Large space & deep excavation required for chambers • Flat & smooth slide way required • Silting may hamper operation • Sector gates: load transfer to hinges, maintenance, corrosion, growth • Floating sector gate complex in operation
Hydraulic and hydrodynamic aspects	
• Limited differential head & horizontal flow contraction in last stage of closure • Excess water: through sluice opening • Suitable for reverse head & flow • Not sensitive to flow vibrations	• Sector gates: ship collision, siltastion in open chambers • Floating sector gate sensitive for reverse head & flow

Floating sector Gate:
Maeslant Storm Surge Barrier, Netherlands (1)



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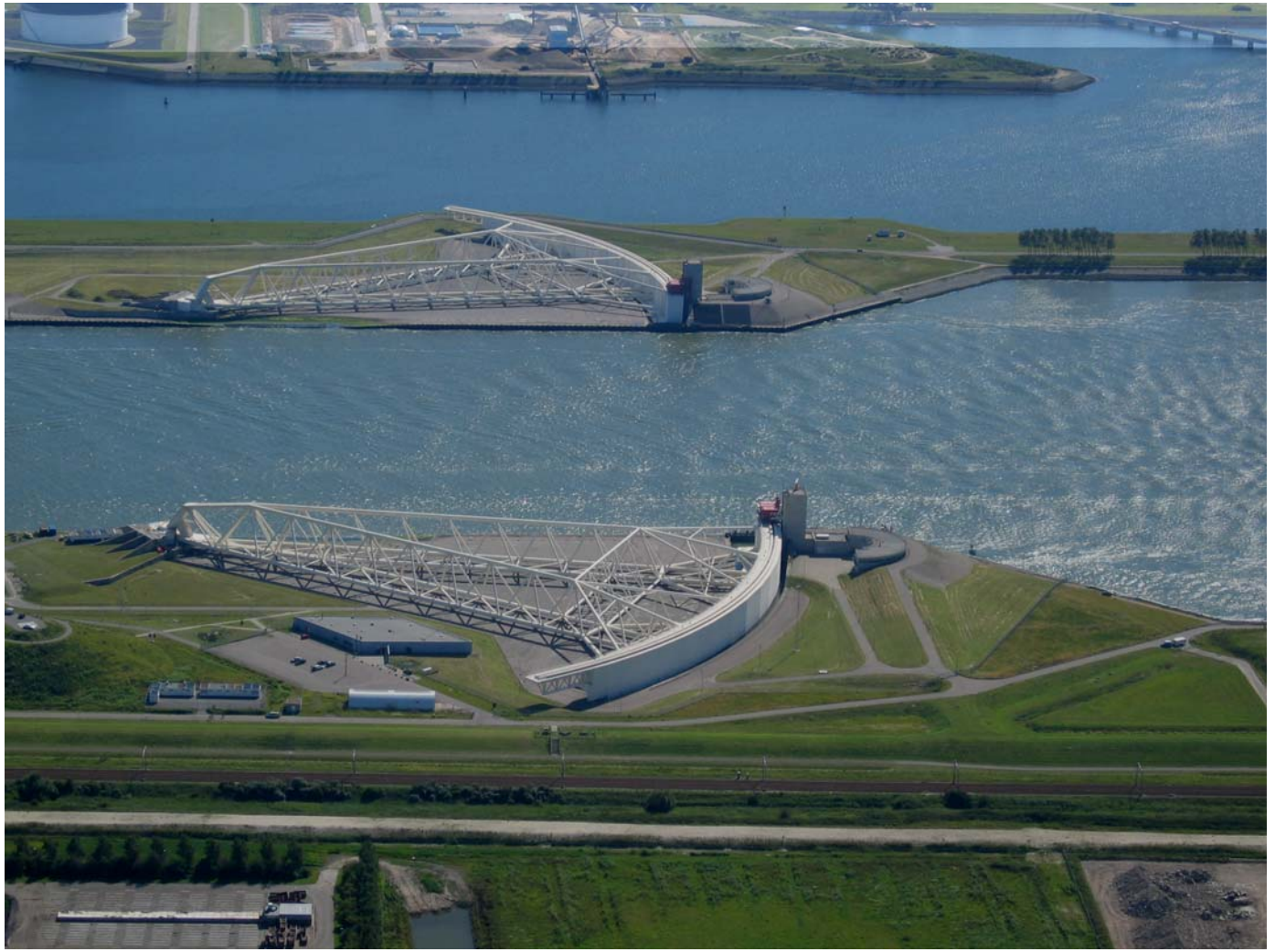
Floating sector gate:
Maeslant Storm Surge Barrier, Netherlands (2)



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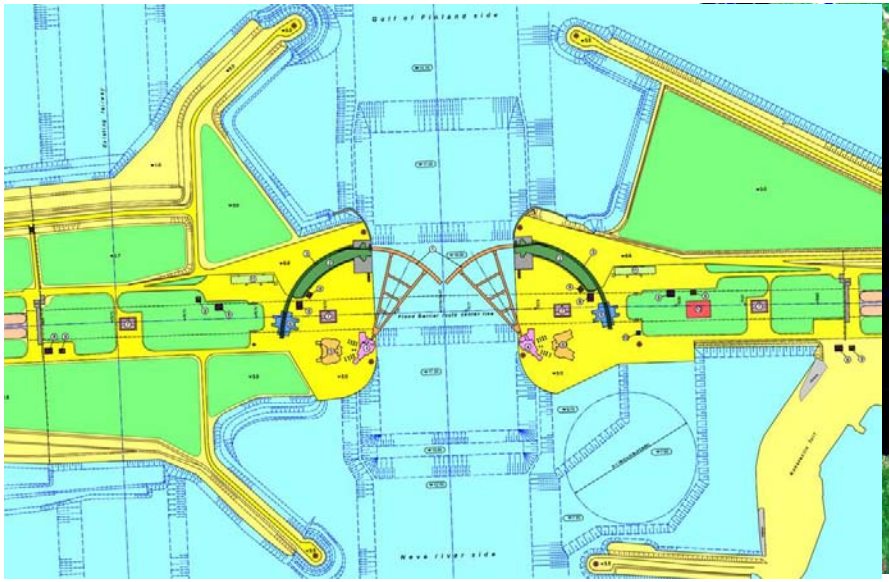
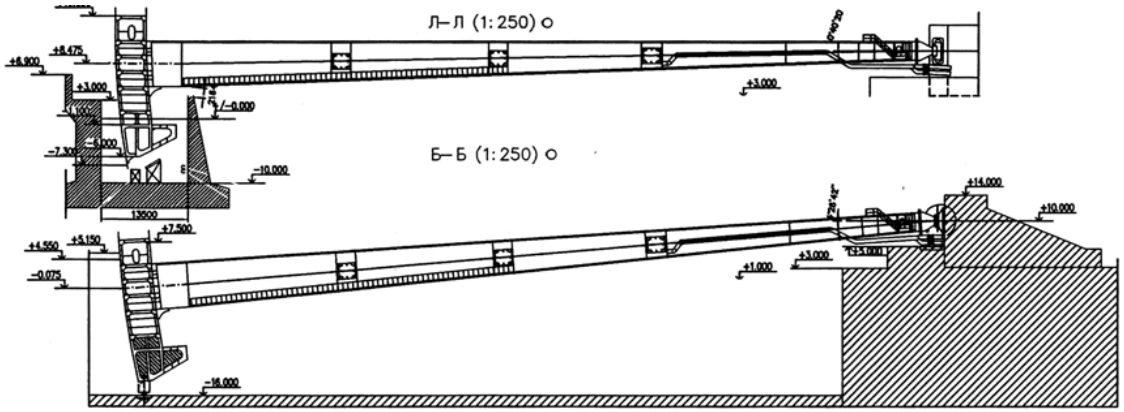
Floating sector gate:
St. Petersburg Storm Surge Barrier, Russia





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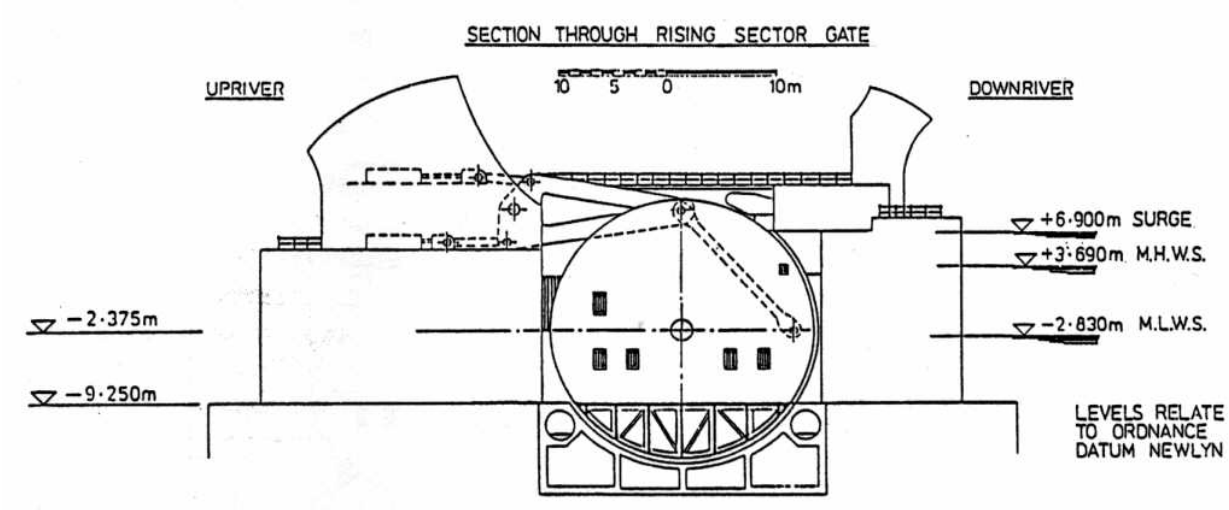
floating sector gates

favorable	unfavorable
Structural aspects, layout and operation	
•Large gate span possible •No clearance height limitation •Shallow dry dock: easy inspection & maintenance and collision protection •Can be immersed if sill covered with sill •No flatness of sill required	•Large space required •Operation complicated, may in flowing water not be fully controlled •A negative differential head my cause problems (pull up forces ball hinges) •Objects on sill can cause damage •Load concentration, forces on hinges •Mobilization time: filling of dry docks
Hydraulic and hydrodynamic aspects	
•vertical closure of flow opening (no strong horizontal flow contraction) •Separate sluice openings may be applied to reduce differential head and discharge excess water	•Sensitivity to flow induced oscillations •Sensitive to dynamic wave forces •Limited resistance to negative differential head

Vertically rotating: Thames Storm Surge Barrier, UK



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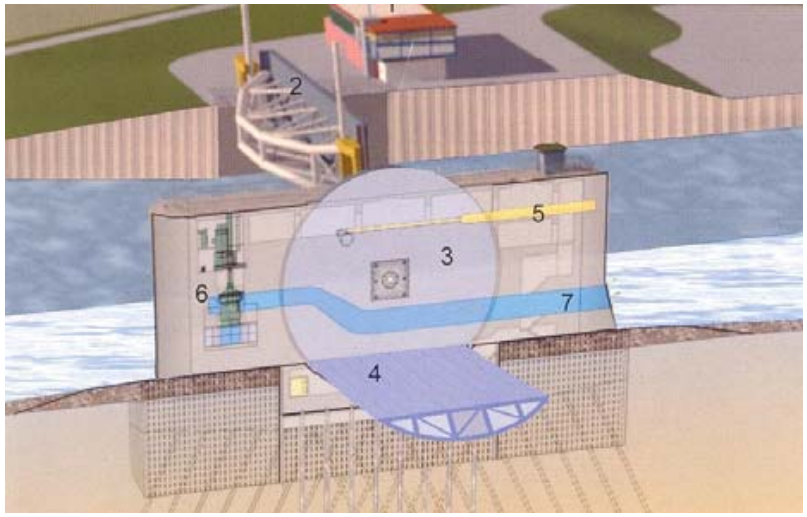
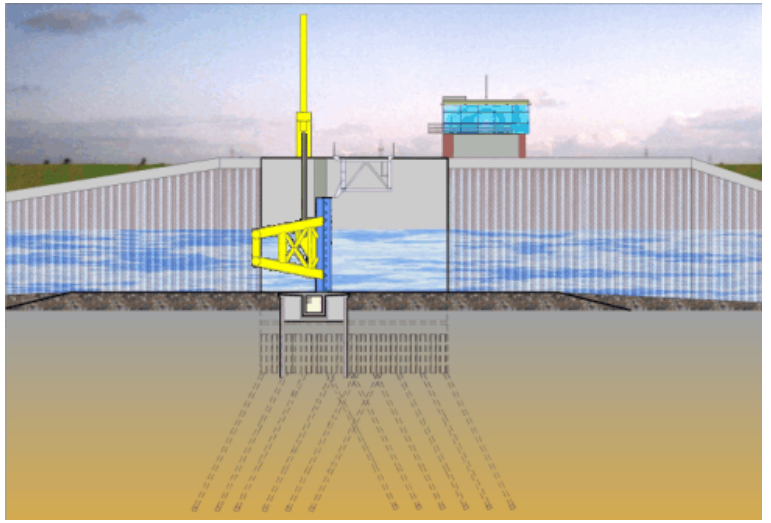
Vertically rotating: Ems Storm Surge Barrier, Germany





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Vertically rotating:
Fox Point Hurricane Barrier, Providence, Rhode Island USA

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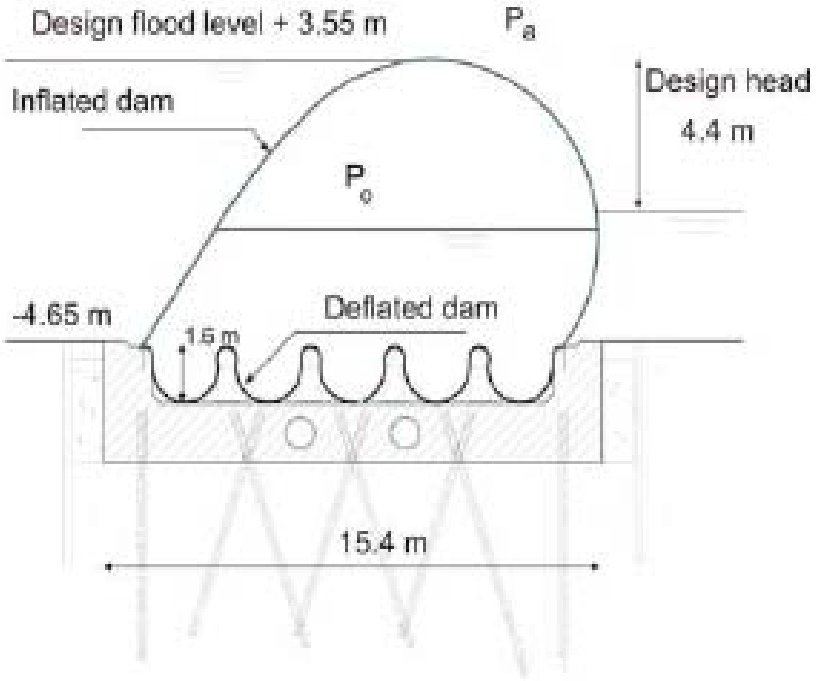
Vertically rotating gates

favorable	unfavorable
Structural aspects, layout and operation	
• Large span feasible • Immediately ready for operation • Controlled operation flow & wave • Little space required • Not subjected to wind • Segment gate: no clearance limitation • Inspection & maintenance	• Load transfer & concentration • Segment gate: high sill tolerance demands, vulnerable to silting, objects, corrosion • Segment gate: access & maintenance • Radial gate: limited clearance height
Hydraulic and hydrodynamic aspects	
• Limited horizontal flow contraction Excess water: through gate • Suitable for reverse head & flow • Radial gate kept free of sill	• Segment gates: sensitive to oscillations in case of overflow • Open gates subject to down pull forces & wave loads

Rubber dams: Ramspol barrier, Netherlands



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Rubber dams

favorable	unfavorable
Structural aspects, layout and operation	
• Large Span feasible • No clearance height limitation • Not subjected to wind • Little space required • Direct transfer of hydraulic load • Invisible when not in use • No need for hinges and operating mechanism	• Flexible structure, low frequencies, small stiffness, great mass • Internal pressure determines stability • Control of storage & immersion of rubber sheet • Not suitable for deep water • Difficult inspection, maintenance, replacement of rubber sheet • Vulnerable for vandalism
Hydraulic and hydrodynamic aspects	
• Vertical closure of the flow opening • Not sensitive to silting of sill	• Ships or objects collision • Strong flow contraction in last stage • Considerable response to wave loads • No spill of excess water, overflow vibrations

Comparison of gate types

	Mitre	V Lift	Flap	Horiz	V rotate	Rubber
Span > 30 m	-	+	+	+	+	+
Span > 100 m	-	-	+	+	-	-
Waterdepth > 10 m	+	+	+	+	+	-
Impact on landscape	+	-	+	+	-/+	+
Maintenance	+	+	-	0	+	0
Currents & waves	-	+	0	0/+	0/+	0
Closure time	+	+	+	+	+	0/-
Space required	+	+	+	-	+	+
Colliding ships	0/-	+	+	0/-	+	0
Reliability	-/+	+	0/+	-/+	+	0
Clearance height	+	-	+	+	-/+	+

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Suitable gate types for New York (1)

- **Mitre gates and rubber dams:**
  - **not suitable regarding span (>100 m) and water depth (> 10 m), resistance against currents & waves**
- **Vertical lifting gates:**
  - **limited width of span: connect a number of gate elements**
  - **clearance height for shipping: combine with a separate shipping lock or with horizontally moving gate or flap gate**
- **Flap gate: could be an option though:**
  - **(under water) maintenance is tough issue regarding tidal currents and sediment flows.**
  - **Also water depths of over 20 m might be challenge**
- **Horizontally moving gates are possible, but:**
  - **required space & risks of colliding ships, risk of a closure failure**
  - **required span for some locations**
- **Vertically rotating gates are a possibility**
  - **limited width of span: connect a number of gate elements**
  - **clearance height for shipping: combine with a separate shipping lock or with horizontally moving gate or flap gate**

Suitable gate types for New York (2)

- Not one perfect gate type for New York
- Combination of gate types, combining the most favorable aspects of several gates could result in the best solution
- Complex tidal water system requires systems approach
- Flood control solutions should be part of an integrated flood risk management system
- Flood gates should always be compared to or combined with other flood risk management measures
- Like dike or levee strengthening, natural coastal protection systems or non structural measures

Concluding remarks

- Costs, construction time, environment, many other aspects have to be taken more into consideration
- Aspects vary with the selected gate type & with design
- No simple decision tree to find the perfect gate
- There is never just one perfect solution
- Consider combining different gate types
- An engineering systems approach is recommended
- A water systems approach is recommended
- Develop a smart water management system

Start with a Deltaplan, like the Dutch: A Hudson Plan!!

Thank you!

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