InCom Working Group 26

Design of Movable Weirs and Storm Surge Barriers

REDUCED VERSION

1st June 2005

SUMMARY

The PIANC InCom-WG26 (Working Group) performed a comprehensive review (state-of-the-art) of the modern technologies, design tools, and recent researches used to design and build structures controlling water level and flow in rivers, waterways, and ports (for navigation and flood protection).

The WG considered regulatory structures of river control weirs and storm surge barriers, focussing on the gate design. This includes:

- Gates controlling water level and flow in rivers (even those not navigable) and waterways (lifting gate, tilting gate, radial gate, sector, etc.; designed in one piece or with an upper flap). These are MOVABLE WEIRS.
- Gates controlling water level and flow in estuaries with regard to high tides and storms (lifting gate, articulated, tilting, rolling, floating, sliding, etc.). These are flood BARRIERS.

The WG Report focuses on the following aspects:

- List of the recent movable weir and barrier projects (see Project Reviews), presentation of their concepts and innovations, and the driving forces considered for selecting these particular designs (Section 2.1).
- A terminology review of the technical terms and names used to define weirs and barriers (Section 2.2)
- Design Procedure for the design of weirs and barriers (Section 3).
- A review of the various multi-criteria assessment approaches that can be used to select the most relevant designs (Section 4). List of criteria for weirs and barriers, are proposed.
- Technical considerations including environmental, economic and safety aspects, for design, construction, maintenance and operation (Section 5).
- Structural considerations on various gate-types with an advantage-disadvantage comparison (Section 5.1).
- Technical background required to perform hydraulic and flow analysis of various gate-types (Section 5.2)
- Interaction between foundation and weir-barrier structure (Section 5.3).
- Control procedures of the gate operations and their maintenance (Section 5.4)
- Survey of the temporary closure systems (e.g. bulkheads) used for inspection and maintenance (Section 5.5).
- State-of-the-art of the risk-based design methods. With applications to navigation weirs and flood barriers (Section 5.6)
- Interactions between the technical aspects of a weir/barrier design with environmental and aesthetic considerations (Section 5.7)
- Procedure to assess the global construction cost of a weir at the design stage (Section 5.8)
- Design assessment tools for preliminary and detailed design stages (Section 6 and Annex A)
- Prefabrication techniques (Section 7)
- Codes, rules and standards: at national and international level; including the use of the semi-probabilistic Eurocode format (Section 8)
- An extensive list of relevant technical books, web sites, and guidelines (Section 10).

The present hardcopy WG-26 report is a reduced version of the full report, which is available on the companion CD-ROM, attached to this PIANC hardcopy report (Directory /A2- REPORT WG-26 (Extended Version)/.

The CD includes

- About 50 Project Reviews of movable weirs and storm surge barriers with various flat, radial, lifting, sector, and inflatable gates (Directory A1 on CD)
- A PDF Copy of this Report (Directory A2 on CD)
- Sponsor Company References (Directory A3 on CD)
- Various additional information about Sections 3; 4; 5; 6; 7 and 8 of this report (Directory Annex Section # on the CD)
- Various technical guidelines (Directories B on CD) such as
  - B1: PIANC's "Illustrated Technical Dictionary" (Locks, Gates, Dewatering services and Protection from Ship Impact).
  - B2: "Design of Mobile and Marine Metallic Structures using the Limit States and Partial Safety Factor Concepts" (France) & "ROSA 2000: Guidelines for the limit state design of harbour and waterways structures"
  - B3: Movable Weirs (Guide du chef de projet)
  - B4: Inflatable Weirs (Germany)
  - B5: Maintenance bulkhead types and Temporary and Demountable Flood Protection. Some technical reports are also given.
  - B6: Examples of rehabilitation Weirs
  - B7: Flood Protection in UK,
  - B8: Environmentally Considerate Lubricants
- WG26's Meeting Pictures, Directory C on the CD

DESIGN OF MOVABLE WEIRS AND STORM SURGE BARRIERS

PIANC WORKING GROUP 26 InCom

CONTENT

WG-26's CD-Rom

- About 50 Project Reviews of movable weirs and storm surge barriers (Directory A1)
- WG-26 Report (FDF Full version), (Directory A2)
- Sponsor Company References (Directory A3)
- Various additional information about Sections 3; 4; 5; 6; 7 and 8 of this report (See Directory Annex Section #)
- Various technical guidelines (Directories B):
  - B1: PIANC's "Illustrated Technical Dictionary"
  - B2: Guidelines: "Design of Mobile and Marine Metallic Structures" & "ROSA 2000:
  - B3: Movable Weirs (Guide du chef de projet - France)
  - B4: Inflatable Weirs (Germany)
  - B5: Maintenance bulkhead types and Temporary and Demountable Flood Protection.
  - B6: Examples of rehabilitation Weirs
  - B7: Flood Protection in UK
  - B8: Environmentally Considerate Lubricants
- WG-26 meeting Pictures, (Directory C)

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The Environment Agency (UK), Voies Navigables de France (VNF), BAW (Germany) and Balkema Publ. for their Copyright Agreements.

Meetings of the Working Group

Working Group (WG-26) had 6 meetings at Brussels (February 2003), London (June 2003), Pittsburgh (November 2003), Rotterdam (March 2004) and Edinburgh (October 2004).

Thanks to the organisations that provided rooms and funded our meetings: TECHNUM and ANAST-University of Liege (BE), British Waterways and the Environment Agency (UK), the U.S. Army Corps of Engineering, INCA (US) and the Rijckwaterstaat (NL).

CD-Sponsors.

The WG acknowledges the following organisations and companies for their sponsorships to support the CD fees: BESIX (B), BRIGESTONE (J. - UK), BRLingénierie (F), CNR (F), COYNE et BELLIER (F), ISM INGENIERIE (F), DYRHOFF as (N), RUTTEN s.a. (B), SCALDIS SALVAGE (B), SVKS (B), VICTOR BUYCK (B)

Extensive technical references of these companies are available on the Directory A3 on the CD.

1. INTRODUCTION

INCOM (PIANC's Inland Navigation Commission) launched, in the last 30 years, working groups (WG) on various subjects such as 'Inland waterway vessels', 'Standardization of ships and inland waterways for river/sea navigation', 'Locks', 'Shiplifts', 'Automatic management of canalized waterways and its hydraulic problems', etc.

For one reason or another, movable weirs, and particularly the design of their movable parts (the gates), have not been addressed by a PIANC WG. While locks, ship lifts, bridges, waterways dimensions, bank protection, contaminated dredge material etc. have been studied, key structures that provide waterway navigability, such as movable weirs, have not.

There are several reasons for this, some of which include the following:

- On rivers, movable weirs are often overlooked. Such is the case of the oldest types (needles, wicket gate, *hausse Aubert, … in France*, and stoplogs). In a similar way bear-trap, radial gates (most of the time) and flap gates are not visible. Only lifting gates are visible throughout the year. Therefore, such "*invisible and quiet structures*" do not seem very important (even if they are usually critical for the surrounding people).
- River weirs are not spectacular. Ships interact with locks, ship lifts, etc. but seldom sail through weirs (unless when is it dismounted or the gate is hidden). River weirs definitely do not attract attention.
- In Europe, most of the rivers are equipped with movable weirs (when required to allow navigation throughout the year). So, most of the projects concern rehabilitation or replacement (as in France) on small rivers having only local traffic and pleasure navigation. This is, of course, less attractive than new outstanding structures. Since about 1970, with infrastructure funds lacking, the emphasis on weirs is no longer a priority (contrary to new canals, locks etc.).
- Movable weirs are massive structures whereas movable parts (needles, stoplogs) are relatively simple and thus do not receive high attention from the head offices.

Field engineers involved in river engineering and particularly those designing river weirs, usually agree that in recent memory, the design of movable river weirs has not progressed as other engineering works have.

- A new weir is usually built like the previous one.
- There is not enough room for innovation, as weir owners (usually public administration) do not want to face any "problems". The risk of using a new concept is usually assessed as being too high as compared to the advantages. This is evidence of how important these gates really are. For standardization reasons (at the operational level), changes are also often avoided.
- Gate type (or weir type) is usually decided based on the experience of the head officer(s) (even if some general assessment is provided). Selection procedure is often more a justification procedure than a thorough investigation for a best solution. Often, various gates types are discarded as not relevant. Then, for the 5 or 6 remaining types, a solution is selected using a series of good and obvious reasons (too expensive, not adapted to sediment transport, movable parts in water must be avoided, too complex, difficult to regulate, aesthetic or integration is doubtful, not reliable, require extensive validation, etc.).

Fortunately, since about 1970, the need to protect estuaries and ports against high tides and storm surges has induced the construction of a new type of movable weirs called barriers. These barriers do not control daily flows for irrigation, navigation or industrial purposes but are designed to prevent a major disaster in case of exceptional high rise of sea/river water level (tide, storm surge, typhoon etc.). Due to the enormous size of these barriers, the traditional conservative designs were avoided and public officers had to challenge designers to develop new and innovative concepts. Outstanding examples are the Thames Barrier, the Nieuwe Waterweg Barrier in Rotterdam and in the near future the Venice Barriers. Such designs required multi-disciplinary teams, thorough economic and technical assessment, multicriteria and risk assessments.

Knowing this situation, this WG report provides some relevant contributions to improve the design (and the gate selection) of movable weirs and storm surge barriers. These contributions are:

- general design methodology
- reviews of the various types of weirs and a listing of new innovative concepts (floating structures, prefabricated elements, inflatable weirs, …)
- an up-to-date review of design tools
- a multicriteria assessment guideline
- a survey of the technical, economical and environmental aspects of movable weirs
- integration of traditional weir design procedures with risk assessment, maintenance and control, codes and standards (Eurocodes), and design concept (limit states and partial safety factors)

It is hoped that, with this information, those responsible for these matters will look at the options in a new light.

1.1 AIMS OF THE WG-26

Based on the WG26's terms of reference the aim of the WG (Working Group) was to conduct a comprehensive review (state-of-the-art) of the modern technologies, design tools and recent research used to design and build structures controlling water level and flow in rivers, waterways and ports (for navigation & flood protection).

The WG considered regulatory structures such as:

- Gates controlling water level and flow in rivers (even non navigable) and waterways (lifting gate, tilting gate, radial gate, sector, etc.; designed in one piece or with an upper flap). These are referred to as WEIRS. This does not include spillway gates of fixed dams. For this specific aspect see ICOLD (www.icold-cigb.org). Irrigation weirs are also not considered in this report. Old weir types such as needle weirs, weir-boards, etc. are not reviewed even though many of these weirs are still used and their improvement investigated.

- Gates controlling water level and flow in estuaries with regards to high tides and storms (lifting gate, articulated, tilting, rolling, floating, sliding, etc.). These structures are referred to as BARRIERS.

The civil engineering aspects related to strength, stability, etc. of the fixed elements (pier, abutments, floor, ..) of moveable structures were in principle not considered unless there is a direct relation between the design of the movable structures and the fixed parts. This is for instance the case of the foundations, as there pattern and strength have a direct effect on the selection of the relevant weir-types and therefore, on the gate-types.

The WG Report focuses on the following aspects:

- List of the recent movable weir and barrier projects (see Project Reviews), presentation of their concepts and innovations, and the driving forces considered for selecting these particular designs (Section 2.1).
- A terminology review of the technical terms and names used to define weirs and barriers (Section 2.2)
- Design Procedure for the design of weirs and barriers (Section 3).
- A review of the various multi-criteria assessment approaches that can be used to select the most relevant designs (Section 4). List of criteria for weirs and barriers, are proposed.
- Technical considerations including environmental, economic and safety aspects, for design, construction, maintenance and operation (Section 5).
- Structural considerations on various gate-types with an advantage-disadvantage comparison (Section 5.1).
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- Procedure to assess the global construction cost of a weir at the design stage (Section 5.8).
- Design assessment tools for preliminary and detailed design stages (Section 6 and Annex A of the report).
- Prefabrication techniques (Section 7),
- Codes, rules and standards: at national and international level; including the use of the semi-probabilistic Eurocode format (Section 8)
- An extensive list of relevant technical books, web sites, and guidelines (Section 10)

1.2 WG26's CD-ROM

Due to editing constraints the number of pages of WG26's hardcopy report was limited. Therefore all the following information have been saved on a companion CD-ROM (attached to this PIANC hardcopy report). This CD includes:

- About 50 Project Reviews of movable weirs and storm surge barriers with various flat, radial, lifting, sector, inflatable... gates (Directory A1)
- Copy of this Report (Full version) in PDF. (Directory A2)
- Sponsor Company's References (Directory A3)
- Various additional information about Sections 3; 4; 5; 6; 7 and 8 of this report (Directory Annex Section #) including a survey of maintenance bulkhead types.
- Various technical guidelines (Directories B) such as:
    - B1: PIANC's "Illustrated Technical Dictionary" (Locks, Gates, Dewatering services and Protection from Ship Impact).
    - B2: "Design of Mobile and Marine Metallic Structures using the Limit States and Partial Safety Factor Concepts" (France) & "ROSA 2000: Guidelines for the limit state design of harbour and waterways structures"
    - B3: Movable Weirs (Guide du chef de projet)
    - B4: Inflatable Weirs (BAW, Germany)
    - B5: Maintenance bulkhead types (survey) and some technical reports are also given. Temporary and Demountable Flood Protection, DEFRA, (www.environment-agency.gov.uk/floodresearch)
    - B6: Examples of rehabilitation Weirs (Belgium, Germany)
    - B7: Flood Protection in UK (Environment Agency)
    - B8: Environmentally Considerate Lubricants (UK)
- WG-26 meeting pictures, (Directory C)

Other relevant documents used by the WG are:

- Manual for River Work in Japan, Japan (In English)

- Technical Standards and Commentaries for Port and Harbour Facilities in Japan (in English).

Unfortunately we were not allowed to paste copies of these 2 documents on the WG26's CD.

1.3 LIST OF PROJECT REVIEWS

The WG completed about 50 project reviews of movable weirs and storm surge barriers. The list is presented in Table 1.1.

The project reviews (full version) are available on the Directory A1 on the CD. Here after is presented (Section 2.1) a brief description of each.

In addition, a descriptive summary of the different weir and barrier types is also available on the Directory A1 on CD.

Code	Gate Type	Project Title	Country	Author	Closure	Purpose
A1	Arch/Visor	Rhine Visor Weirs	NL	Daniel	Frequent	Flow
A2	Arch/Visor	Osaka Arch Gate	Japan	Nagao	2-3 / Year	Flood
B1	Flap Gate	Lagan Weir(Storm surge barrier)	UK	Dixon	Frequent	Flow
B2	Flap Gate	Tees Barrage (Tidal weir)	UK	Dixon	Frequent	Flow
B3	Flap Gate	Libcice-Donaly (river navigation weir)	Czech Rep	Kupsky	Frequent	Flow
B4	Flap Gate	Veseli (24m long)	Czech Rep	Kupsky	Frequent	Flow
B5	Flap Gate	Bremen Weser Weir (navigation weir)	Germany	Meinhold	Frequent	Flow
B6	Flap Gate	Torque-tube at Montgomery Dam	USA	Stockstill	Annual	Flow
B7	Flap Gate	Sauer Closure Gate - Short Review	France	Daly	Frequent	Flood
B8	Flap - Wicket	Denouval	France	Daly	Frequent	Flow
B9	Flap - Wicket	Olmsted, Wicket Gates	USA	Stockstill	Annual	Flow
B10	Flap - Inflatable	Sinnissippi Weir (Obermeyer)	USA	Lagache	Frequent	Flow
B11	Flap - Bouyant	Venice storm surge barrier	Italy	Perillo	Annual	Flood
C1	Inflatable Weirs	Inflatable Weir	Canada	Abdelnour	Frequent	Flow
C2	Inflatable Weirs	Ramspol Barrier	NL	Daniel	Annual	Flood
C3	Inflatable Weirs	Pocaply (river weir)	Czech Rep	Kupsky	Frequent	Flow
C4	Inflatable Weirs	Inflatable Weirs Presentation	Germany	Meinhold	Frequent	Flow
C5	Inflatable Weirs	Rubber Dam at the river Lech	Germany	Meinhold	Frequent	Flow
D1	Miter Gates	Goole Caisson	UK	Dixon		Emergency
E1	Radial - Single	Upper Meuse	Belgium	Hiver	Frequent	Flow
E2	Radial - Single	Steti (river navigation weir)	Czech Rep	Kupsky	Frequent	Flow
E3	Radial - Single	Stör Storm Surge Barrier	Germany	Meinhold	Frequent	Flood
E4	Radial - Single	Braddock Dam	USA	Miller	Frequent	Flow
E5	Radial - Single	Iron Gates (Nagivation river weir)	Romania	Sarghiuta	Frequent	Flow
E6	Radial - Single	Olt River Lower Course	Romania	Sarghiuta	Annual	Flow
E7	Radial - Double	Eider Barrage (storm surge barrier)	Germany	Meinhold	Frequent	Flood
E8	Radial - Double	Haringvliet Storm Surge Barrier	NL	Daniel	Annual	Both
E9	Radial - Innovative	Radial Gate w/ Under/Overflow (Concept)	Belgium	Rigo	Frequent	Flow
E10	Radial - Innovative	Prefab Floating Weirs: Alu + Fibres Conc	Belgium	Rigo	Frequent	Flow
F1	Rolling & Trolley	Selby Lock Rolling Gate	UK	Dixon	3 per year	Flood
F2	Rolling & Trolley	Berendrecht Flood Control Rolling Gate	Belgium	Bulckaen	Annual	Flow
G1	Roof or Bear Trap	Tee Gate	UK	Dixon	Frequent	Flow
H1	Sector - Horiz.	Roudnice (river weir)	Czech Rep	Kupsky	Frequent	Flow
H2	Sector - Horiz.	Mosel River Weir Lehmen(Nav. Weir)	Germany	Meinhold	Frequent	Flow
H3	Sector - Rising	Thames River Barrier	UK	Wilkes	5 - 30/year	Flood
H4	Sector - Rising	EMS (storm surge/nav. Channel gate)	Germany	Meinhold	Frequent	Both
I1	Sector - Vertical	Maeslant Storm Surge Barrier	NL	Dan.& Bulk.	Annual	Flood
I2	Sector - Vertical	Storm Surge Barrier: Alternative Concepts	NL	Rigo	Frequent	Flood
I3	Sector - Vertical	Amagasaki ock gate	Japan	Nagao	2-3 / Year	Flood
J1	Stoplogs & B/H	Kentucky Lock Floating Caisson	USA	Miller	Annual	Flood
J2	Stoplogs & B/H	Olmsted Maintenance Bulkheads	USA	Miller	Annual	Flood
J3	Stoplogs & B/H	Tees Stoplog	UK	Dixon	Annual	Maintenance
J4	Stoplogs & B/H	Murray River Stop Logs	Australia	Rigo	Frequent	Flow
K1	Swing	Bayou DuLarge : 17m Barge Gate	USA	Miller	Annual	Flood
K2	Swing	Bayou Lafourche Barge Gate	USA	Miller	Annual	Flood
K3	Swing Floating	Storm Surge Barrier: Alternative Concept	BE, NL	Rigo	Frequent	Flood
L1	Vertical Lift	Beernem Weir	Belgium	Bulckaen	Frequent	Flood
L2	Vertical Lift	Hartel Canal Barrier	NL	Daniel	Annual	Flood
L3	Vertical Lift	Ivoz-Ramet (Renovation weir + B/H)	Belgium	Dermience	Frequent	Flow
L4	Vertical Lift	Kamihirai Gate	Japan	Nagao	2-3 / Year	Flood
L5	Vertical Lift	Shinanogawa River Gate	Japan	Nagao	2-3 / Year	Flood
L6	Vertical Lift	Blanc Pain (Emergency gate)	Belgium	Rigo	Frequent	Emergency
L7	Vertical Lift	Hull Barrier	UK	Wilkes	10-30/year	Flood
L8	Vertical Lift	Cardiff Bay	UK	Wilkes	Frequent	Tide
M1	Floating boom	Ice Boom - Lac St. Pierre	Canada	Abdelnour	Annual	Flood
M2	Unclassified	Curtain Barriers – Temporary	Canada	Abdelnour	Annual	Flow
	Maintenance Bulkheads and Cofferdams- *See CD Annex Section 5.5*			Rigo	Annual	Maintenance

Table 1.1 : List of Project Reviews

2. GATES OF MOVABLE WEIRS AND BARRIERS

2.1 PROJECT REVIEWS

Representative samples of each gate type included in this document are summarized in this chapter. Case studies of each of these gates are included on the WG25-CD /Directory A1/. The case studies include a more complete description of the gate, foundations, abutments, operating characteristics and, where available, cost. Photographs and select engineering drawings are also presented for many of the gates.

A. ARCH or VISOR GATES

An arch gate is a three-hinged arch that spans from abutment to abutment across the waterway. It is hinged at the abutments and rotates upward for storage and downward to close the channel.

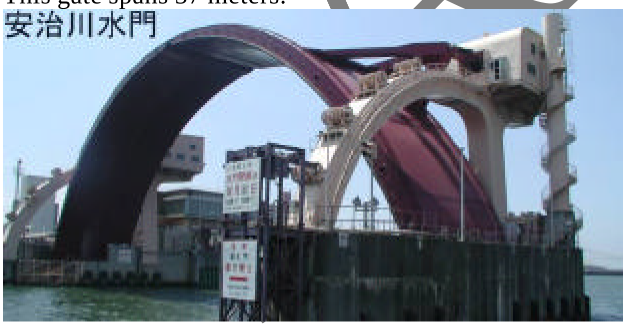
A.1 Rhine Visor Weirs

These double visor gates each span 54 meters and are used to control flow for power generation and navigation. This is one of 3 weirs of similar construction on the Rhine River.

Hagestein, The Netherlands (~1960)

A.2 Aji River Barrier

This is one of 3 lock gates constructed as flood protection measures from storm surges for the city of Osaka, Japan. This gate spans 57 meters.



Osaka, Japan, 1970

B FLAP GATES

Flap gates are hinged along the upstream edge of the gate and attached to a sill foundation. They are stored submerged and flat to the bottom. To close the flow, the downstream edge is rotated upward.

B.1 Lagan Weir (Storm surge barrier)

The barrier is composed of 5 Fish Belly, bottom hinged, flap gates. Each gate is 20m wide by 4.5m tall. These gates are used for flood control and to improve water quality.

Belfast, Northern Ireland, 1994

B.2 Tees Barrage (Tidal weir)

This barrage was established to improve water quality and to provide flood protection. The barrage has 4 bottom hinged fish-belly flap gates. Each gate is 13.5m wide by 8m high.

Stockton on Tees/Teesside, UK, 1995

B.3 Libcice-Dolany (river navigation weir)

The three sluiceway openings serve navigation and hydropower interests on the Vltava River. The right sluiceway is 19.85 m wide and the others are 43.0 m, with a control height of 3.3m.

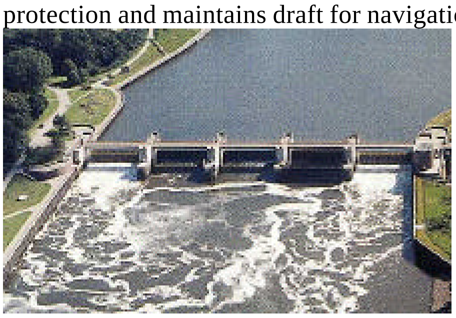
Libcice, Vltava River, Czech Republic, 1989

B.4 Veseli (24m long)

The weir Veselí consists of two 24.4 m wide hollow flap gates with a 1.4 m control head. The dam provides support for navigation and hydropower. A fish ladder is also provided.

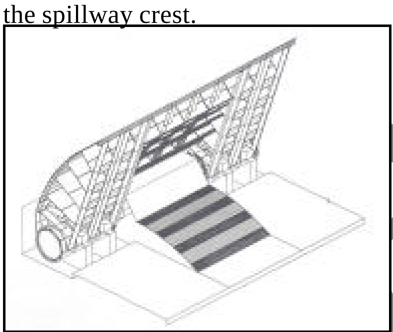
Veseli, Morava River, Czech Republic, 2002

B.5 Bremen Weser Weir (navigation weir)
The five fish belly flap gates span 31 m and provide a control height of 3.8m. The weir provides for flood protection and maintains draft for navigation.



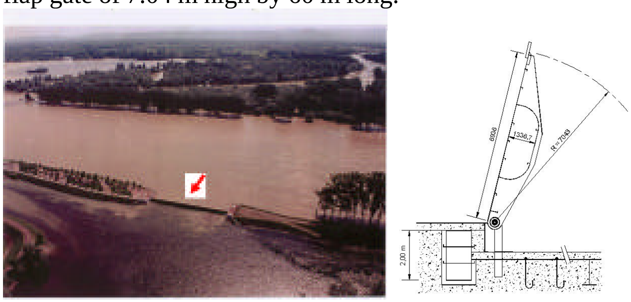
Bremen, Germany, 1993

B.6 Torque-tube at Montgomery Dam
The project consists of a navigation lock, a 91.4-m-wide controlled navigation pass spillway with 10 torque-tube gates, and a 61.0-m-wide fixed uncontrolled overflow spillway. Each gate is 9.1 m wide and rises 3.96 m above the spillway crest.



Desha County, Arkansas, USA, about 2004

B.7 Sauer Closure Gate
The goal of this project is the protection of cities and lands against flood created by the river Rhine. There is a single flap gate of 7.04 m high by 60 m long.

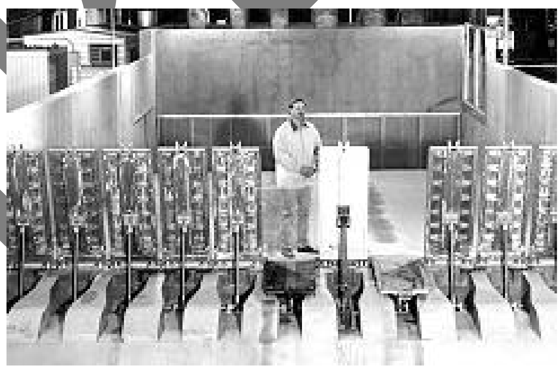


Sauer Flood Barrier – Munchhausen, France, 1993

B.8 Denouval Wicket Gates
These 30 wicket gates dam a river width of 70 m. Each wicket has a height of 3.3 m and a width of 2.5 m. The gates are hydraulically operated and can be placed in one of four possible positions. The gates facilitate navigation on the Seine.

Andresy, Seine River, France, 1980

B.9 Olmsted Wicket Gates
The navigable pass section of the dam will be 420-m long with 140 x 2.95-m wide, boat-operated steel wicket gates. The project provides navigation and flood control.



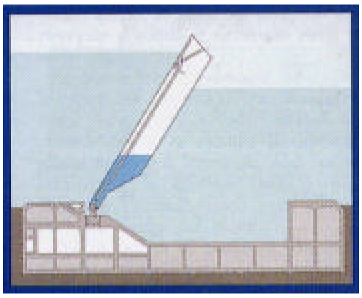
Olmsted, Illinois, USA, Estimated 2009.

B.10 Sinnissippi Dam
The dam has three 16m (48-foot) long and four 32m (96-foot) long pneumatically operated hinged-leaf gates and a 168m (504-foot) long conventional concrete ogee spillway and provides for flood protection, hydropower and navigation (Obermeyer system).

Sterling – Rock Falls, Illinois, 2002

B.11 Mose Buoyant Flap Gate

These oscillating buoyant retractable floodgates will provide flood protection to Venice. Seventy-eight flood gates will be provided at 4 locations. They will vary in width from 3.6m to 5m and the length will vary from 18 to 28m.



Venice, Italy (planned project)

C INFLATABLE WEIRS

These are operable weirs that are composed of long bladders, secured to a bottom foundation. The weir is raised by inflating the bladders with air or water.

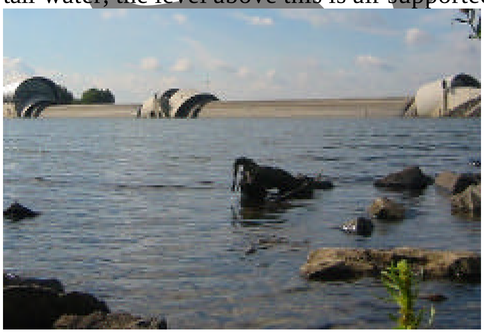
C.1 Canadian Inflatable Weir

An inflatable weir was built upstream of a fall, downstream from a power plant intake structure, to control and optimize the water level while maintaining a minimum flow over the weir at all times.

Chute Bell, Rivière Rouge, Québec, Canada, 1994

C.2 Ramspol Barrier

These 3 inflatable fabric bellows barriers with a width of 60m, provide 2.7m of flood protection from inland river flood waters. The water level inside the barrier matches the tail-water, the level above this is air supported.



Kampen, the Netherlands, 2002

C.3 Pocaply Inflatable Weir

This rubber dam is 21m wide with a design height of 1.6m. It is water filled and provides a pool for hydropower generation.

Pocaply, Loucna River, Czech Republic, 1998

C.4 German Inflatable Weir Reference Document

This pdf document shows a presentation on the operation and design of inflatable weirs (BAW, Germany).

C.5 Rubber Dam at the river Lech

This dam provides a pool for hydropower. Four sections are used, one with a width of 26.65m and a height of 3.35m. The other three are 46.67m wide by 1.25m high.

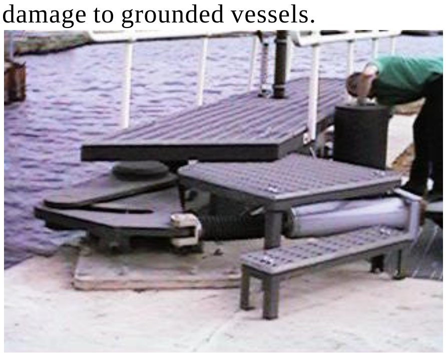
Füssen, Germany, 2001

D MITER GATES

Miter gates are typically used for navigation locks rather than flood control. However, they are used at Goole to prevent the harbour draining if the canal wall collapses. Miter gates are only operated when the water level is equal on both sides of the gate. A miter gate has two leaves that are hinged like doors on either side of the channel. They meet at an angle of about 30 degrees and rely on the mitering action to span the opening. This carries significant thrust to the abutments.

D.1 Goole Caisson

These gates are closed if a breach in the canal wall occurs. This prevents the harbour from draining with subsequent damage to grounded vessels.



Goole, Great Britain, 2002

E RADIAL GATES

A Radial or Tainter gate has a skin plate mounted on an open structural steel frame supported by strut arms at each side of the gate. The strut arms extend to trunnion bearings mounted on abutment walls on either side of the gate opening. Radial gates may have the trunnion bearing either upstream or downstream and the gates may be stored submerged and raised to close flow or stored overhead and lowered to close flow.

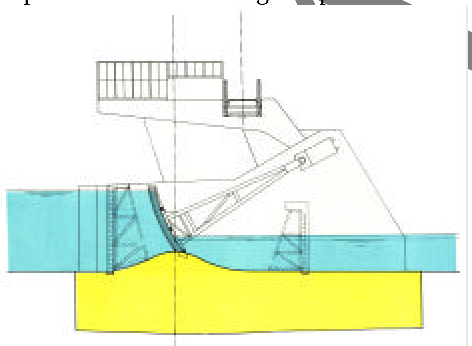
E.1 Upper Meuse

This project will rebuild a number of locks and dams on the upper Meuse River to improve navigation and power generation. These radial gates have an upper flap that allows more economical and precise flow control.

Upper Meuse Basin, Belgium, 1985-95

E.2 Steti Radial Gates

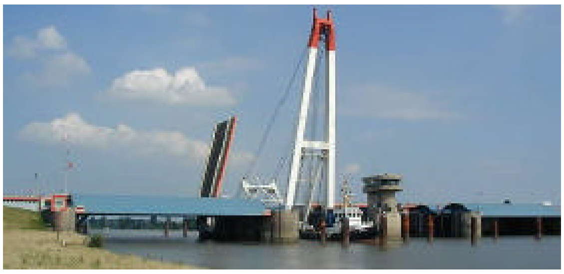
The weir is provided with seven sluiceway openings, two are fixed, two are locked by a steel radial gate, and three openings are locked by a steel radial gate with a control flap. 4.4m of control height is provided.



Steti, Labe River, Czech Republic, 1972

E.3 Stör Storm Surge Barriers

Double Tainter gates are provided on each side of two lock chambers to provide redundant flood protection in support of navigation. The tainter gates span 43 m and are 13 m high.



Federal State Schleswig-Holstein, Germany, 1974

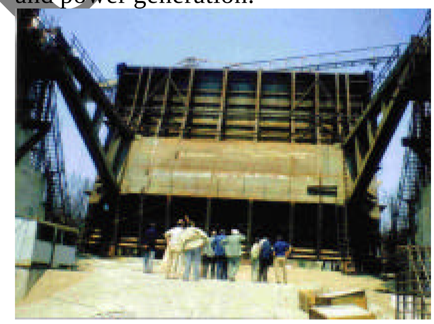
E.4 Braddock Dam

The 4 radial gates are 33.53m long with a total damming height of 6.4m. The gates are used for flood protection and navigation and are hydraulically operated.

Braddock, PA, USA, 2003

E.5 Iron Gates

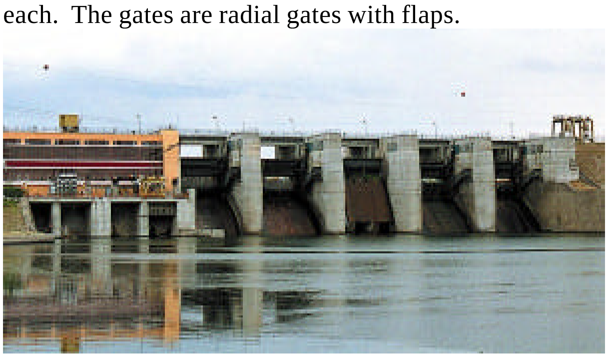
The two spillway dams on each river branch with seven 21m wide gates, three of which are equipped with overflow flaps of 2.50 m height. The dams are used for navigation and power generation.



Danube, Romania and Yugoslavia, 2000

E.6 Olt River Lower Course

Five dams were constructed in 13.5m steps along the Olt River to provide for hydroelectric power generation. Each of them consist of a gated dam with 5 openings of 15 m each. The gates are radial gates with flaps.



Olt River – lower course, Romania, 1990

E.7 Eider Barrage (storm surge barrier)

The floodgate section consists of five 40m wide spillways. Each opening has two radial floodgates for double protection. Seaside: High: 10.1m Riverside: High: 11.10 m

Schleswig-Holstein/Nordfriesland, Germany, 1973

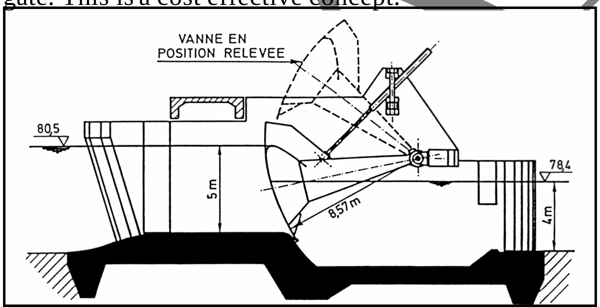
E.8 Haringvliet Storm Surge Barrier

This flood control structure provides two rows of 17 seaside and 17 riverside radial gates. The barrier is 1048.5m wide and the gates span 62m.

Hellevoetsluis, The Netherlands, 1970

E.9 Radial Gate with Under and Overflow

This gate concept has not yet been implemented, but would allow fine control of flow by lowering the gate and allowing surface flow over the top or would provide for high discharges and passage of sediment by raising the gate. This is a cost effective concept.



Upper-Meuse, Belgium (not built)

E.10 Prefabricated Floating Weirs - Innovative Concept

A series of 9 prefabricated navigation control weir sections are constructed in 4 floating sections that are transported afloat to the site and placed on a prepared foundation. Elements are made of aluminium to float in shallow water (60cm) steel can also be used. The structure (30m long, 29.5m wide and 7.6m high) includes 2 radial gates of 12m. The infill concrete is reinforced with steel fibbers rather than traditional rebar. This facilitates underwater placement.

The concept was developed for the Sambre river, Belgium, (not yet built).

F ROLLING or TROLLEY GATES

Rolling and Trolley gates are closure panels stored adjacent to the waterway. They are rolled into position in anticipation of a flood event. Rolling gates are bottom supported and trolley gates are top supported.

F.1 Selby Lock Rolling Gate

This flood control gate is stored in a slot at the side of the waterway and is winched across the canal. The gate is 6.4m wide, 3.85m high and 0.35m deep. It is partially buoyant and seals to a timber sill.

F.2 Berendrecht Flood Control Rolling Gate

These rolling lock gates are used to provide navigation access through a flood control barrier. The gates are buoyant and supported by a submerged trolley on the leading edge and an above water trolley on the aft end. The gates are 69.69 m long and have a height of circa 22.60 m. The average width is 9 m.

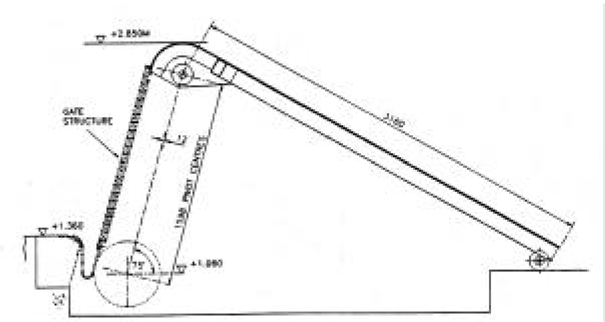
Antwerp, Belgium, 1989

G ROOF or BEAR TRAP GATES

Bear trap gates are not as common today as in years past. A bear trap gate is constructed of two leaves that slide over one another and seal together. They are stored on the bottom of the waterway. Typically water is allowed to enter the space beneath the gate and the upstream water pressurizes the space beneath the leaves and the gate leaves rise to block the flow. Resurgence has been found in two projects in England. They are used in recreational water parks to provide a "whitewater" rafting and canoeing experience. The course is configurable by adjusting the bear trap gates to adjust the flow characteristics. One example is provided at Tees Barrage in England.

G.1 Tees Barrage Bear Trap Gate

This bear trap gate is 5.950 m wide. The upstream leaf is 1.598 m centre to centre and the downstream leaf is 3.160m. The gate is used to control flows for white water canoe and kayak recreation.



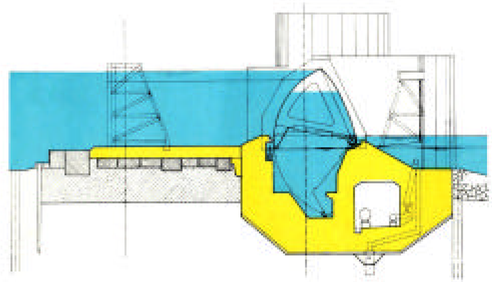
Tees, United Kingdom,1984

H SECTOR GATES - HORIZONTAL AXIS

Horizontal axis sector gates are circular sections hinged on the downstream side with a skin plate on the upper 2 sides. A horizontal axis sector gate rotates in a vertical plane about a horizontal axis. When lowered the upper skin plate of the gate coincides with the overflow section of the sill. Rotating or Rising sector gates are included here also. These gates provide skin plates on a segment of a circular arc and are supported at the sides of the spillway.

H.1 Roudnice

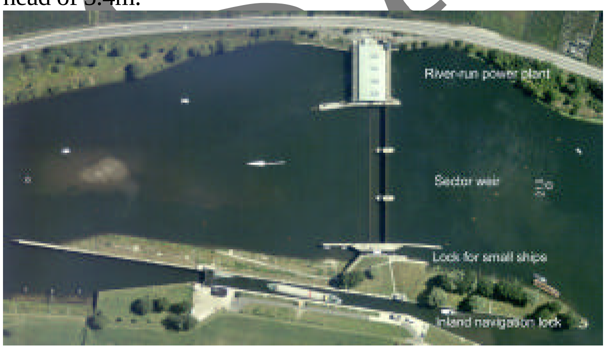
These gates are used for navigation and irrigation. Three sluiceways of the same clear width of 54.05m span the river with a dam height of 2.70 m



Roudnice, Labe River, Czech Republic, 1972

H.2 Mosel River Weir Lehmen (Navigation Weir)

11 of the 14 weirs built on this section of the Mosel use sector gates to control flows for navigation and hydropower generation. Three 40m spans dam an upstream head of 5.4m.



Mosel river, Germany,1963

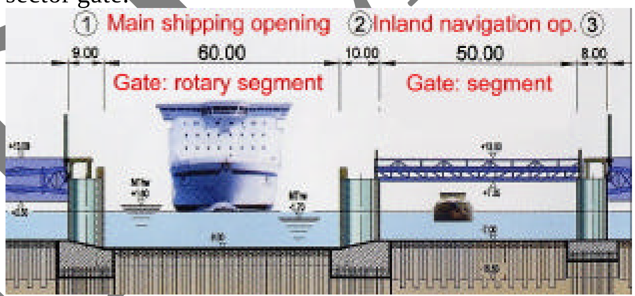
H.3 Thames River Barrier

This massive flood protection barrier protects London from flooding on the river Thames. The barrier extends 520m across the river and uses four 20 m high rising sector gates that span 61m.

London, United Kingdom, (1982)

H.4 Ems Barrier

The Ems barrier provides flood protection and supports navigation, it has a length of 476m between bank lines with 7 openings. The main shipping opening uses a rotating sector gate.



Ems river, Germany, 2002

I SECTOR GATES - VERTICAL AXIS

Vertical Axis Sector Gates are circular sections supported on a vertical hinge at the center of a circular arc. The skin plate is only on the face of the circular arc. Because the hydraulic thrust is directed radially inward toward the vertical axis there is very little unbalanced load and they can be opened and closed with differential head across the gate.

I.1 Maeslant Storm Surge Barrier

This flood protection barrier spans 360m. The gate is made buoyant when it is moved by locomotive engines on each shore. The gates pivot on specially fabricated spherical bearings.

Hoek van Holland, Netherlands, 1997

I.2 Maeslant Alternative Barriers

This paper discusses the alternatives to the sector gates finally selected for the Maeslant barrier. A pneumatic tumble gate, a segment gate, hydraulic tumble gate, sliding gate, boat gate and floating sector gates are discussed.

I.3 Amagasaki lock gate

These Vertical axis sector gates provide 17m wide lock access for navigation while providing flood protection to the lowland city from offshore storms and surges.

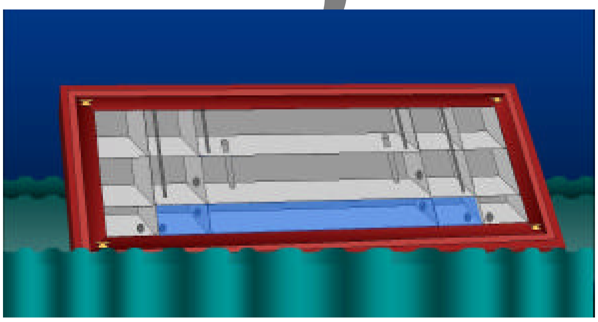
Amagasaki City, Japan, 2003

J STOPLOGS and BULKHEADS

Stop Logs and Maintenance bulkheads are typically constructed with a pair of horizontal trusses supporting a vertical skin plate on one face. They are stored separately from the gate opening and lifted into place by an overhead or mobile crane. They are designed to span across the opening or between intermediate posts that can be installed at intervals across the opening. They may extend vertically from the sill to the top in one piece or smaller units may be stacked and seal against one another to close the opening.

J.1 Kentucky Lock Floating Caisson

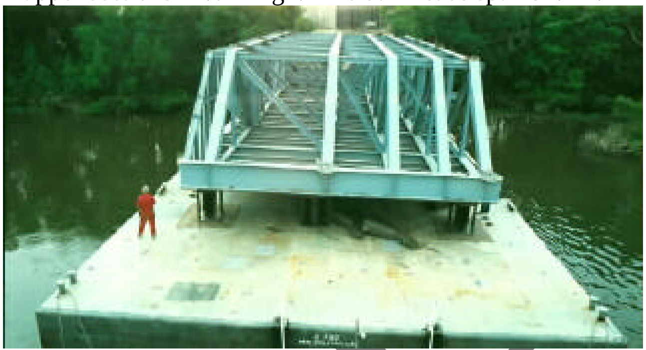
This floating gate is used to dewater lock chambers for maintenance. The bulkhead is towed from one site to another as a barge. It is then filled with water in a sequence to rotate it vertically, move it into position, and lower it into final position. The gate is 34.3m wide and 9m high with a depth of 3.2m.



Locks on Tennessee & Kentucky Rivers, USA, 1969

J.2 Olmsted Maintenance Bulkheads

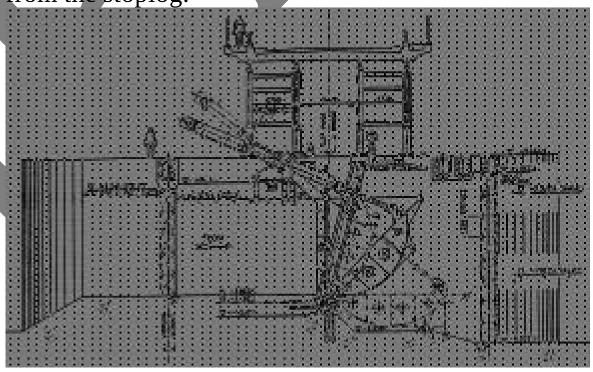
Four bulkhead sections were built to allow maintenance dewatering of the locks and radial gates. The bulkheads are stacked to meeting varying site conditions. Two lower sections 3.4m and 5.5m high are designed to support one of 2 upper sections 11.6m high. The bulkheads span 34.1m.



Olmsted, Illinois, USA, 2004

J.3 Tees Stoplog

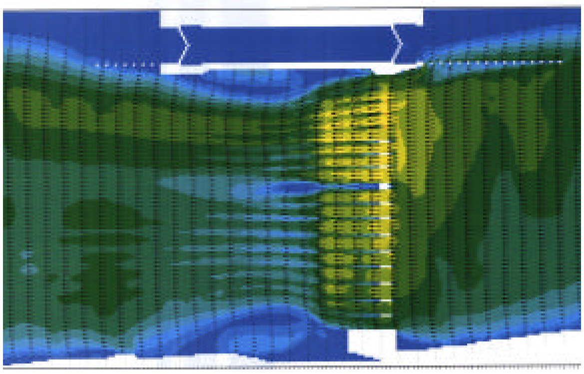
Thirteen stoplogs, 1.25 m high, close an opening 13.89m wide. Eight are used on the downstream side of a gate bay and 5 are used upstream. They are placed with a crane and a lifting beam that will automatically engage or disengage from the stoplog.



Stockton on Tees/Teeside, UK, 1995

J.4 Murray River Stop Logs

These stop logs are used in support of navigation and flood control. They resist heads varying from 4.5 to 6m



Between Adelaide and Mildura, Australia, around 2000

K SWING GATES

A swing gate is stored on one side of a waterway and pivots about a vertical axis to close against abutments on either side of the waterway. A Swing Gate may be buoyant to reduce hinge and operating forces.

K.1 Bayou DuLarge Barge Gate

This flood control barrier is made buoyant and floated into position by winches in advance of a flood. It spans 18.3m. When in position, it is ballasted onto the sill and has a height of 6.25m.

Bayou DuLarge, Louisiana, USA, 1996

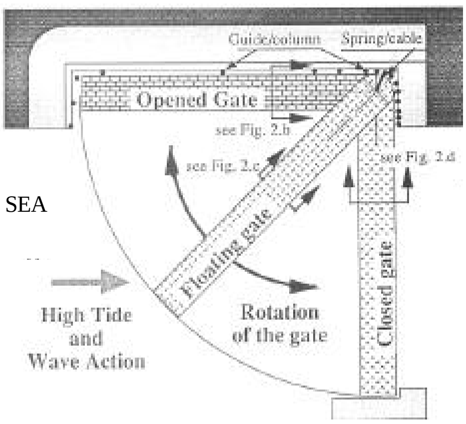
K.2 Bayou Lafourche Barge Gate

This flood control barrier is similar to Bayou DuLarge. It spans 22.9m and has a depth of 3m with a water-tight parapet extending up an additional 1.5m.

Bayou Lafourche, Louisiana, USA

K.3 Antwerp and Rotterdam Swing barriers

This innovative concept of floating rotating barrier was developed for closure of large spans (up to 400m) without any limitation on draft or air clearance, during construction or operation (Rigo et al. 1996).



Project in Belgium and The Netherlands (not built)

L VERTICAL LIFT GATES

Vertical lift gates are raised and lowered vertically. They may be stored underwater and raised to close flow, or stored above a channel on towers and lowered to close flow.

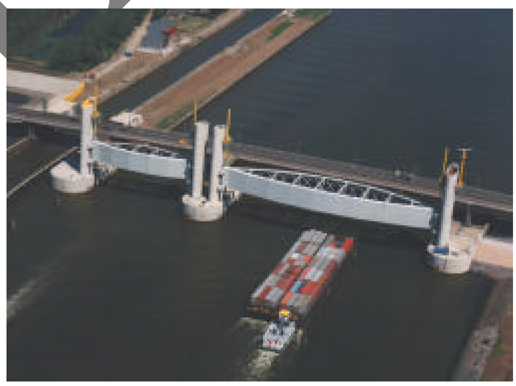
L.1 Beernem Weir

This vertical lift gate provides flood protection and is 8.05m high and 17.9m wide.

Beernem, Flanders, Belgium, 1998

L.2 Hartel Canal Barrier

This large storm surge barrier consists of two lens-shaped vertical lift gates with spans of 98m and 49.3 m with a height of 9.3m. To facilitate water storage the gate never fully closes and at high flood stages the gates are overtopped.



Spijkenisse, Netherlands, 1996

L.3 Ivoz-Ramet

This is a nice example of a rehabilitated weir.

Liege, Meuse River, Belgium, 2000-2001

L.4 Kamihirai Gate

These 4 gates are closed in advance of a flood event. Each gate is 30m wide, 2 gates are 9.2m high and the other 2 are 9.5m

Tokyo, Japan, 1990

L.5 Shinanogawa River Gate

This flood protection structure has 3 spans each 30m wide with a height of 24.5m.

Niigata prefecture, Japan, 1974

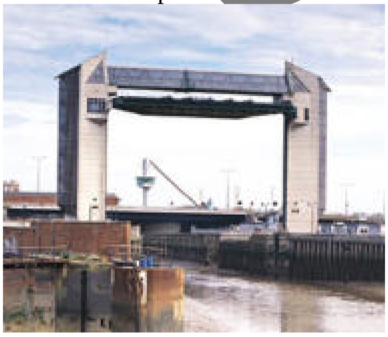
L.6 Blanc Pain

This emergency lift gate protects the 73m high shiplift at Strépy and the surrounding countryside from a flood event in the event of riverbank or structural collapse. The gate closes a channel width of 32.4m and has an air clearance of 7m when raised.

La Louvière, Canal du Centre, Belgium 2003

L.7 Hull

The flood protection barrier is a vertical lift gate which provides a 30 meter wide navigation opening and provides 6.3 m of flood protection.



Hull, UK, 1979

The gate is designed to be aesthetically pleasing and the gate rotates 90 degrees when raised to maximize navigation clearance and minimize visual impact.

L.8 Cardiff Bay Barrier

Cardiff Bay Barrage is a tidal exclusion barrier designed for flood control with 5 sluices (9m wide x 7.5 m high) with double-leaf vertical lifting gates (Faganello E., 2004).

Cardiff Bay, UK, 1998-99.

M UNCLASSIFIED GATES

M.1 Ice Boom - Lac St. Pierre

This floating structure protects a major shipping channel from closure by ice. The floating boom segments are restrained by steel cables to anchors on the lake bottom.

Trois Rivières, Québec, Canada, 1994

M.2 Curtain Barriers – Temporary

This curtain barrier was designed to create a headloss and temporarily force the diversion of the flow away from a tributary. The barrier consists of a long steel pipes with a curtain attached to the bottom. The curtain can be a rubber liner or a plastic pipe(s).

Laboratory test and the field deployment of a curtain, 2004.

2.2 TERMINOLOGY REVIEW

2.2.1 TECHNICAL TERMS IN DIFFERENT LANGUAGES

2.2.1.1 PIANC Dictionaries

To promote the use of homogeneous technical terms in different languages the PIANC's *Illustrated Technical Dictionaries* (written in the six languages: French, German, English, Spanish, Italian, and Dutch) may be very helpful.

Since 1930 different PIANC dictionaries have been published. Unfortunately, some have not yet been published or are no longer available. These dictionaries (published or not) are:

- Chapter I: The Sea (*)
- Chapter II: Rivers, Streams, Canals (*)
- Chapter IV: Boats and Ships, Propulsion (1967)
- Chapter V: Materials (1951)
- Chapter VI: Construction Plant and Methods (1959)
- Chapter VII: Ports (1938)
- Chapter VIII: Locks and Dry Docks, (1936)
- Chapter IX: Maritime Signals (1963)
- Chapter X: River Weirs (Fixed weirs & Movable weirs), (1935, *)
- Illustrated Technical Dictionary (PIANC, 1985, Draft)

(*) Not (or no longer) included in the actual PIANC-Catalogue

The *Dictionnaire Technique Illustré* (PIANC, 1985) is currently unpublished. It's content concerns elements of locks, power stations, weirs, dewatering systems, impact-protection systems and different equipment-parts belonging to them. The draft includes terms concerning water and hydraulic engineering and terms for special hydraulic steel structures (different lock and weir gates).

Nevertheless a draft is available in four languages (German, English, French, and Dutch) but it is not fully complete. The dictionary, converted in PDF-files, can be found on CD, Directory /B1- DICTIONARY (PIANC 1986)/.

The Table of Contents (pdf-files) includes:

- Page 02-19: Locks (Types, Elements, Cross-Sections)
- Page 20-41: Gates (Including Equipments)
- Page 42-53: Dewatering Devices
- Page 54-57: Protection from Ship Impact
- Page 58-65: Water Levels / Navigation Conditions

2.2.1.2 ELSEVIER'S Dictionary

The Dictionary *"Water and Hydraulic Engineering"* (Elsevier 1987) is also recommended. This dictionary contains translations in English, French, Spanish, Dutch and German.

2.2.1.3 ICOLD's terminology

ICOLD (International Commission on Large Dams) has also edited a valuable terminology guideline, which mainly relates to gates of spillways rather than river navigation weirs.

The ICOLD website contains the reference to their technical dictionary,
http://www.icold-cigb.org/anpubli.html
and there is also an online dictionary at:
http://www.icold-cigb.org/services.htm

2.2.2 Standard technical terms of gates of movable weirs and barriers

Before starting with the technical aspects of weir design, it is necessary to introduce the following information:

- The types of barriers and weirs and main characteristic dimensions.
- The name (terminology) of the constitutive elements of barriers and weirs.

Here after technical terms are explained using pictures and sketches (self explanatory pictures).

Figure 2.1 shows a generic view of the main elements of a movable weir structure and its movable parts (hydraulic steel constructions) and the meaning of the terms (associated with numbers of this figure) are given below.

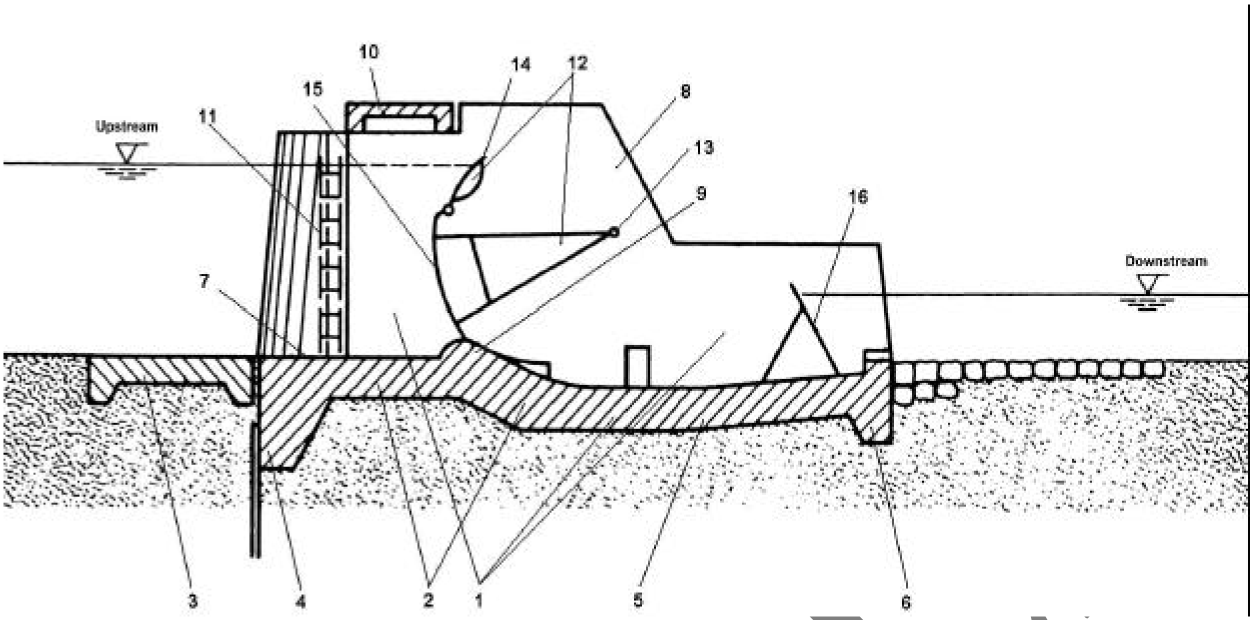


Figure 2.1 : Generic view of the main elements of a movable weir structure

Number	Meaning
1	Weir structure
2	Weir sill (or slab)
3	Upstream floor
4	Upstream diaphragm wall (or apron) with cutoffs (here sheetpiles)
5	Stilling basin
6	Downstream diaphragm wall (or apron)
7	Intake floor
8	Weir pier
9	Sill
10	Service bridge
11	Upstream dewatering structure or Bulkheads (here: stop logs)
12	Gate (here: radial gate with fishbelly flap)
13	Bearings
14	Breaker (for flow aeration)
15	Upstream face (water retaining front of the gate)
16	Downstream dewatering structure or Bulkheads

Some generic types of gates of movable weirs are presented below on Table 2.1 to Table 2.3.

Table 2.1: Generic types of gates of movable weirs (Part I)

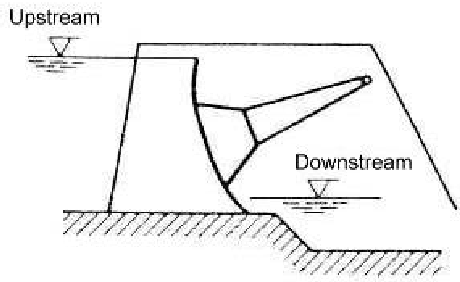
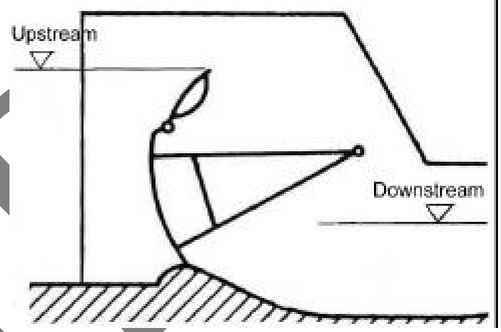
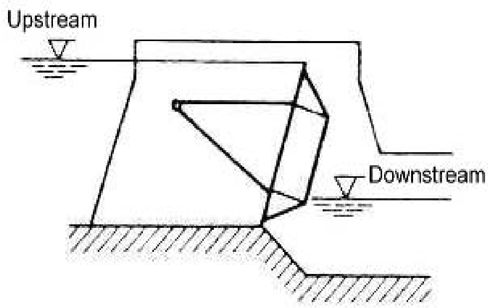
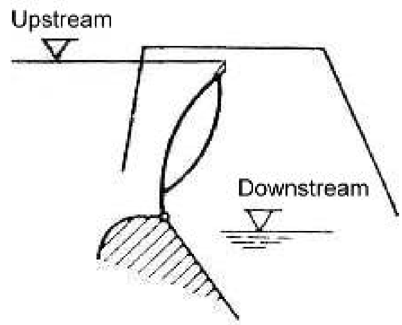
Code	**Gate type** in English German (D), French (F) and Dutch (NL)	**Sketch of gate-type**
1	Radial or taintor gate with compression gate arms D: Drucksegment F: Vanne segment avec bras en compression NL: Segmentschuif	
2	Radial gate (or Taintor Gate) with compression gate arms and upper flap gate D: Drucksegment mit Aufsatzklappe F: Vanne segment avec un clapet supérieur NL: Segmentschuif met klep	
3	Radial gate (or Taintor Gate) with tension gate arms D: Zugsegment F: Vanne segment à bras tendu NL: Segmentschuif met trekarmen	
4	Flap gate (Fishbelly-type) D: Stauklappe, Fischbauchklappe F: Vanne Clapet NL: Bodemklep	

Table 2.2 : Generic types of gates of movable weirs (Part II)

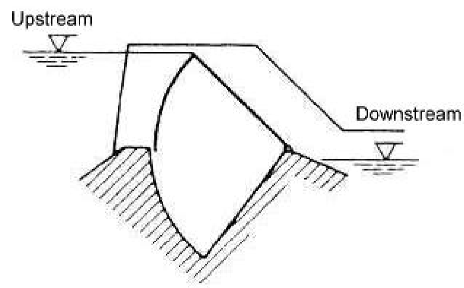
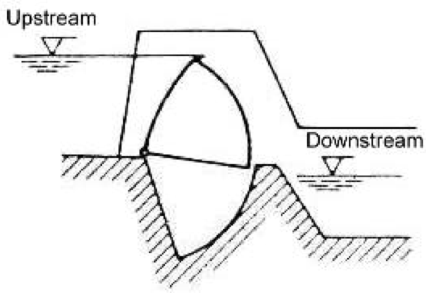
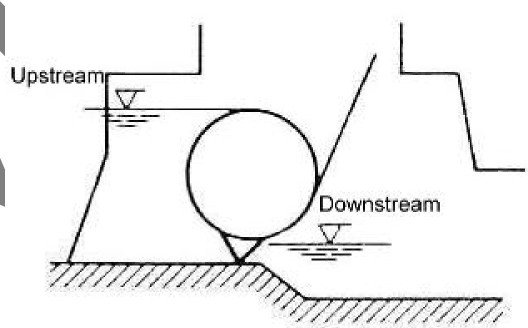
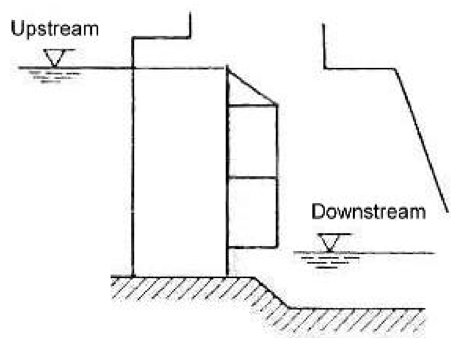
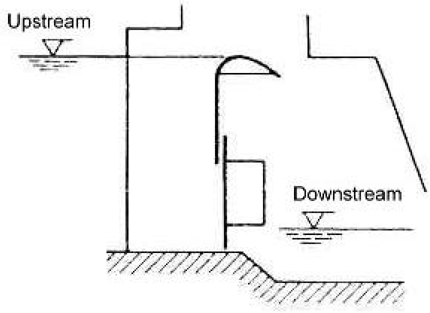
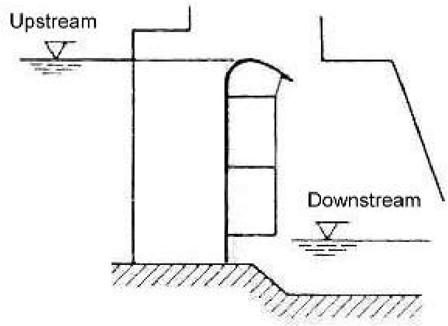
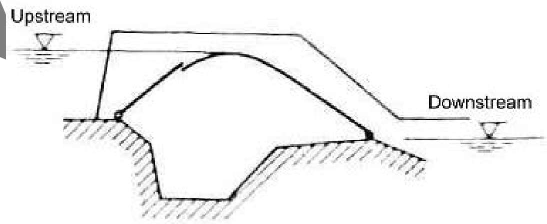
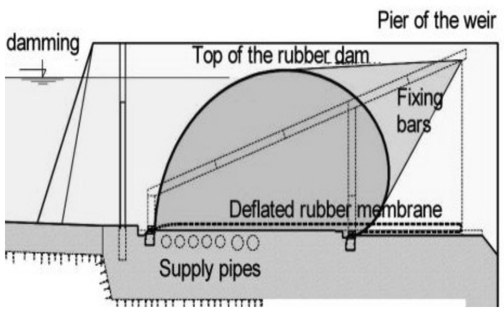
Code	**Gate type** in English German (D), French (F) and Dutch (NL)	**Sketch of gate-type**
5	Sector gate D: Sektor F: Vanne secteur NL: Verticale sectordeur	
6	Drum gate D: Trommel F: Vanne Tambour NL: Luchtkistdeur (trommeldeur)	
7	Roller drum gate D: Walze F: Vanne Cylindrique NL: Cilinderdeur	
8	Vertical lift gate (one-piece gate) D: Einteiliges Hubschütz F: Vanne levante (en une pièce) NL: Hefschuif	

Table 2.3 : Generic types of gates of movable weirs (Part III)

Code	**Gate type** in English German (D), French (F) and Dutch (NL)	**Sketch of gate-type**
9	Double leaf gate (Upper gate: Lifting hook type) D: Hakendoppelschütz F: Vanne levante avec hausse supérieure NL: Dubbele hefschuif met overlaat	
10	Vertical lift gate (Lifting hook type) D: Hakenschütz F: Vanne levante avec lame déversante NL: Hefschuif met overlaat	
11	Beartrap gate, roof weir D: Doppelklappe, Dachwehr F: Vanne toit NL: Dubbelklep, dakstuw	
12	Inflatable weir / Rubber dam D: Schlauchwehr F: Vanne gonflable NL: Balgstuw	

3. DESIGN PROCEDURE

This section provides a summary of the design procedures of the controllable weirs and gate structures essential for safe operation under environmental or other loading conditions expected during its operational life.

As an introduction (WG26-CD Directory /B3…/), the reader should note that the Voies Navigables de France (VNF) published a comprehensive guide "*Les Barrages Mobiles de Navigation*", for use by the project manager to design movable navigation weirs (VNF 1998).

Other publications worth mentioning are the U.S. Army Corps of Engineers "*Engineering and Design, River Hydraulics*" (1993) that discusses the design criteria for hydraulic structures including locks, dams, gates and spillways. "*Hydraulic Design of Navigation Dams*" (1987), "*Vertical Lift Gates*" (1997) and "*Design of Spillway Tainter Gates*" (2000) are other pertinent sources published by the U.S. Army Corps of Engineers.

Many of the existing documents on movable structures are very elaborate and detailed, and should be used as references. For examples: Bouvard (1991), Burt (1996) and Mockett et al. (2003).

The design procedures of movable gates and barrier structures include a number of steps and associated parameters, which are (Figure 3.1):

- Site Parameters, as the selection of the site, depends on several factors (called here parameters).
- Required Information such as bathymetry, water discharge, wind magnitude, … and Loads that are necessary for technical analysis at concept development and later for the weir structure design.
- Navigation and Operational Requirements such as debris flow protection, navigation safety, sedimentation … that correspond to the user requirements to have save, efficient and reliable operations of the weir.

Design Criteria that help the development of a preliminary analysis by assessing the degree of applicability of each type of structure to the proposed project site.

4. DESIGN PROCEDURES FOR MOBILE WEIRS AND STORM SURGE BARRIERS

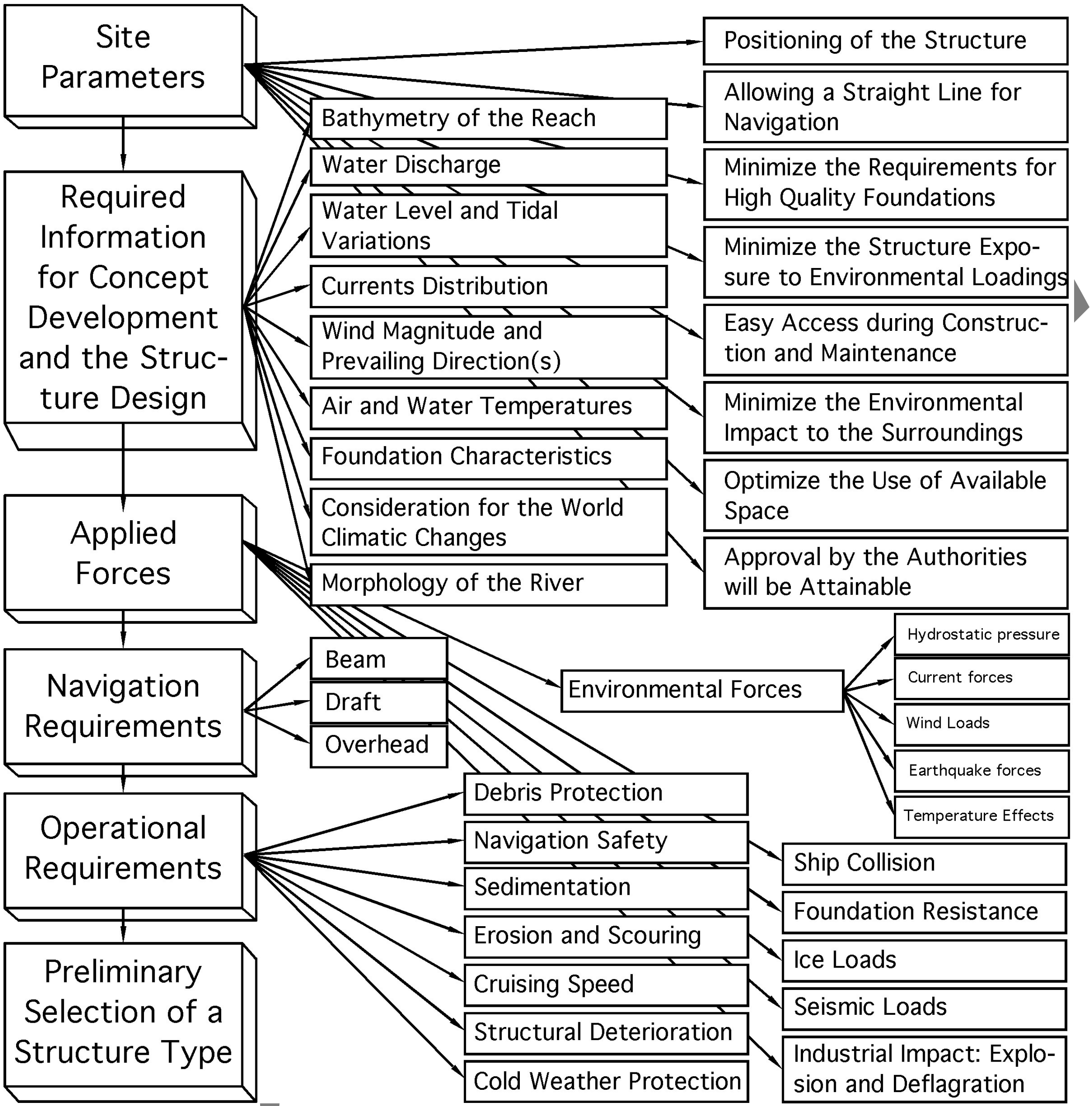


Figure 3.1: Design procedure for Controllable Weirs and Gate Structures

MULTI-CRITERIA ASSESSMENT

4.1 NECESSITY OF A MULTI-CRITERIA ASSESSMENT

Both river movable weirs and costal barriers are structures that have great economical, environmental, and other impacts to large areas. The weir and the barrier projects usually affect many people in many different ways, varying from the safety of their homes to the nature of their means of income. The processes, which generate these effects, are often complex, and can be short-term (e.g. immediate solution to flood problems) as well as long-term (e.g. agricultural, ecological, or even climatic changes).

A gate type selection is a significant part of these processes. There are far-reaching consequences of choosing one gate type above another. Though gate type selections usually take place when the global project requirements are known, they can still affect such principal issues as:

- Weir/gate location – as not all gate types are suitable for all locations;
- Waterway navigability – as the gate type selected may promote or halt navigation.;
- Flooding risk – as not all gate types are equally stable, watertight etc.;
- Water flows, bottom and shore erosion – as different gates give different flow patterns;
- Water ecosystem – as not all gate types allow, for example, for a fish passage;
- Local economy – as gates can provide one kind of work and/or destroy another;
- Local energy balance – as gates can be suitable for energy generation or not.

It should, therefore, be clear that the gate type selection is a matter of engineering, economy, politics, or any other privileged discipline, and its people. It is, in fact, a matter of the entire communities living or having other interests in the areas in question. These communities and areas can be very large. In extreme cases, different interests in this matter result in international disagreements. For practical reasons, the gate type selection is usually made by the engineers. They should, however, be aware of all different interests involved; and seek a balance between those interests. The gate type selection can be assisted using multi-criteria assessment methods.

5. DESIGN CONSIDERATIONS (Parameters and Criteria)

5.1 STRUCTURAL CONSIDERATIONS

The aim of this section is to give an overview about the gate structural aspects and to survey the advantages and disadvantages of the structural aspects of the various gate-types for their intended purposes. These advantages-disadvantages will vary according to how closely the gate type matches its expected uses.

The assessment of the advantages and disadvantages of various gate-types can only be considered and performed for a given context and situation. It is necessary to provide a complete investigation of the local site characteristics, the user requirements and the design objectives (weir functions) before an effective assessment of gate types can be made.

If the situation-context changes, then the advantages and disadvantages of a given gate also change. Therefore, the limits of use and the optimum ranges of application of a gate-type can vary with the operational requirements (barrier or river flow control weir, rural or industrial area, etc.).

This chapter will first present the Main Steps of a Structural Design (Section 5.1.1), and then present three additional areas of consideration for gate selection:

- Structural Characteristics of various gate-types (Section 5.1.2).
- Analysis of specific constraints and functions (Section 5.1.3).
- The Typical Structural concerns (problems, malfunctions) that may occur in movable weirs (Section 5.1.4),

The last section (5.1.5) of this chapter compares the advantages and disadvantages of the design, construction, maintenance and operational characteristics for each of 5 major gate types. The typical range of operation and use are provided to assist the designer in selection of the most appropriate gate type for a specific application.

5.2 HYDRAULIC AND FLOW

This section evaluates various gate configurations from a hydraulic perspective. The discharge characteristics are quantified in terms of discharge coefficients (where available), that is, the head/discharge relation. Vibration tendencies that may be associated with the gate geometrical configuration or seal locations are identified. Gate performance in regards to their ability to control flow/pool by throttling flow is compared. Some gate types lend themselves to simply a fully open or fully closed operation. Another issue that can be important is the speed of gate operation. What type of gates can be opened or closed rapidly relative to other choices. Venting of the lower nappe of the jet is required for certain types of gates to avoid harmful vibrations. A gate's efficiency at passing floating material such as ice and debris can be an important project consideration. Wider gates are more efficient at passing floating material and are better at avoiding jams of floating material between piers. Effects of high tailwater, potential for unusual hydrodynamic loads, and potential for problems associated with sediment accumulation are also addressed.

A list of hydraulic performance evaluation metrics is provided. Each of the gate types is described in terms of these metrics (where metrics have been identified in the literature). Any appurtenances that should be avoided (e.g. a seal location) or included (e.g. air vent for nappe aeration) are also mentioned.

5.3 FOUNDATION AND CIVIL ENGINEERING

This subtask intends to emphasize the main aspects of foundations and civil works related to movable weirs and storm surge barriers. The foundation of movable weirs and storm surge barriers shall be designed to be safe against loads transmitted from the weirs and barriers body, to possess the required water tightness against seepage flow.

The regional and site geologic setting are critical in evaluating the adequacy of a proposed weir or barrier and a given situation (e.g. site location). The foundation conditions available may have a significant effect on the site arrangement, on the design of the structure and on the sequence of construction.

The sele ction of the most appropriate foundation type is largely based on the site geology, the available geologic and geotechnical information, as well as the performance requirements of the foundation. The type of structure should also be considered. The final decision on the foundation type will affect the total project cost. Foundation investigations and field data are required to assess whether or not a safe and economical structure can be built at a selected site (Fig. 5.1). Especially, in a seismic environment and in locations where differential settling is expected will affect the foundation design. Therefore, foundation investigation is one of the most important issues at the design stage.

Investigations to collect such information are conducted in the field and in the laboratory. Analyses and reference work are performed in the office.

Additionally, the seismic environment of the site will affect the design of the foundation. At the feasibility stages the designers should undertake an appropriate seismic risk assessment and must be aware that some sites are not suitable for barriers, barrages, or dams.

Fig. 5.9(a): Collapse of the Shih-Kang weir (Taiwan)

Fig. 5.1(b): Collapse of a we ir due to foundation failure.

For instance, the Shih-Kang weir (Taiwan) was designed with 2 sluiceways and 18 spillway gates. On September 1999, the concrete weir was severely damaged during an earthquake of magnitude 7.3, and the reservoir was released through two destroyed spillway gates (Fig. 5.1). The most spectacular damage occurred near the right abutment and was due to fault movements (reverse faulting) of several metres mainly in the vertical direction. During the excavation of the dam foundations, no fault trace was detected or reported. From this case, it can be concluded that dams cannot be designed economically to resist fault movements of such magnitude (Wieland, 2003).

5.4 CONTROL, OPERATION AND MAINTENANCE

5.4.1 INTRODUCTION

This section investigates the control systems used on the Movable Weirs and Barriers reviewed by the WG. The investigation should enable an informed decision on the advantages and disadvantages of the various systems in use and assist in the selection of a control system for a new construction.

As well as the control functions of the mechanical, electrical and computer systems the investigation shall include the controls imposed on the operation by statutory bodies such as the Environment Agency in England and VNF in France (see their web sites in Section 10.1).

The investigation will also consider operational aspects including the manning implications of the systems adopted and the method to isolate the gate for maintenance.

5.4.2 METHOD

A detailed questionnaire was sent to each reporting member, along with guidelines to assist in its completion. Both the guidelines and the questionnaire are available on the CD-Directory /Annex Section 5.4 /. This was followed by further questions depending on the issues raised within the initial response, either specific to a structure or to satisfy a global issue. The results from the questionnaires and the author's own experience was used to complete the task.

5.5 TEMPORARY CLOSURE ARRANGEMENTS

5.5.1 DEFINITION OF 'TEMPORARY'

It is important to separate "maintenance closure" from "emergency closure" and "site construction closure" systems. This report mainly deals with maintenance closure.

Typically, emergency closure systems are vertical-lift gates that remain suspended. They are expensive systems.

Few emergency systems were considered in the WG's Project Reviews (Blanc-Pain Gate in Belgium and the Hartel Canal in the Netherlands).

Site construction closure systems can be quite similar to maintenance closure. The "Pallet Barrier" is probably the best example.

For our purposes, a temporary closure is defined as either:

- a closure required to make the structure available for maintenance or repair.
- a closure required to ameliorate the effects of a flood event or breach where no fixed device is available.

Examples for the first situation would be stoplogs used to seal off a structure so it can be dewatered and accessed for maintenance.

For the second it could be the use of a floating cofferdam brought to the site of a breach in the canal bank or a damaged gate and deployed to control the leak until a permanent repair can be carried out.

5.5.2 CLOSURE DEVICES OR BULKHEADS

A *bulkhead* is a vertical partition used to seal off one space from another, capable of withstanding the differential head without significant deformation or leakage. Bulkheads are a variation on Stoplogs and are generally one piece construction rather than sectional or modular.

There are several devices capable of being deployed to be a temporary closure. A few common examples are:

- Stoplogs (**Erreur ! Source du renvoi introuvable.**, **Erreur ! Source du renvoi introuvable.**)
- Needles (**Erreur ! Source du renvoi introuvable.**)
- Cofferdams
- Caissons
- Air or water bags
- Palets, etc.

5.6 SAFETY, RELIABILITY AND RISKS

5.6.1 USE OF RELIABILITY AND RISK

5.6.1.1 Definitions

<u>Reliability analysis</u> (REA) means the investigation towards the probability that a structure or part of a structure (existing or to be designed) will not fulfil its task.

Increasing complexity of structures and their equipment (machinery, electrical/electronical systems and so on) have increased dangers to society and the environment and have increased the importance of reliability as a quality characteristic.

The determination of the probability of function loss, or probability of failure, is important, because the probability of failure has to remain between economical and legal restraints.

Very generally, reliability is defined as the probability that an item will perform a required function:

- Under specified conditions,
- For a specified period of time.

Reliability, as the characteristic of a structure or a structural element, is expressed as a probability, which includes three independent concepts:

- Time,
- Spatial factors (such as operating, maintenance, and environmental conditions),
- Rules for determining whether or not the structure or part of a structure performs as specified (definition of failure).

Reliability of a structure (or also of a product) can be defined as a function of time, because time is the only factor that changes for every device.

<u>Risk</u>

A lot of discussion is still going on in the scientific world upon the use and definition of risk. An overview can be found in Vlek (1996). Informal definitions of risk, such as "a set of possible negative consequences" or "lack of perceived controllability" which all are an expression of uncertainty, also exist but will not be used in this text.

The following definition of risk is frequently used in the engineering community because of its ability to quantify the risk:

> *"Risk is the measure of the probability and severity of an adverse effect to life, health, property, or the environment (an adverse impact). The scale or significance of risk is described by a combination of probability of failure (reliability) and consequences of a particular outcome or set of outcomes. Probability and consequences can be multiplied together to assess the size of a risk. "*

An example shows the shortcomings of this definition: a 0.5 probability (or 50% chance) of incurring a loss of 1000 EUR may be considered similar, in risk terms, to a 0.01 probability (or 1% chance) of a loss of 50000 EUR. Both have mean or mathematical expectation values of 500 EUR within the time period. Despite their similar risk values, attitudes to and management of these risks may differ because of their very different scales of loss, should they arise. Therefore, for the complete assessment of risk, it may be necessary to take into account the component probabilities and consequences.

A **<u>Risk-Analysis</u>** (RIA) links the different possibilities of failures and the current probability of their appearing with the consequences belonging to them.

A reliability analysis is a part of a risk analysis. In a risk analysis, not only the probability of failure is determined, but also the material and immaterial consequences. Since damage is also related to local circumstances (is there industry and/or housing downstream the failing gates, or agricultural land, or natural areas…?), it is difficult to generalize the results of a risk analysis.

5.7 ENVIRONMENTAL IMPACTS AND AESTHETICS

5.7.1 ENVIRONMENTAL IMPACTS

It is recommended that clients, designers and planning authorities are mindful of the "*whole life cycle*" impact of their projects – it would be unfortunate if a chosen design was resource effective at the building stage, but proved resource intensive during operation and posed major wastage and impact at decommissioning.

Similarly, it is important to consider the "*whole environmental footprint*" of the project and not just factors relevant to the site of construction and operation. For example, avoid specifying timber or stone from sources which are not sustainably managed and/or require transport over large distances; instead, use more innovation in the specification and seek out managed, local sources of materials.

As with so many designs and conceptual processes, recognise that achieving high standards of environmental acceptability is an iterative process – allow one good idea to lead into another.

Environmental headings that must be considered include:

- Storage and handling of all materials;
- Construction materials;
- Materials, resources and energy required to operate;
- Impacts, particularly waste streams at times of major overhaul, e.g. removal and surface preparation from old paint, especially over water.

Some of the UK standards such as the Institution of Civil Engineers CEEQUAL Standards, BREEAM standards for buildings and the Environment Agency's own Environmental Audit provide much useful guidance (http://www.ceequal.com/ and http://www.bre.co.uk/).

Inspired environmental design will also consider the impact of the installation in its locality. Factors, which should be considered, include:

- The scale of disruption to natural tidal regimes or fluvial flows. A major impact is likely to be bad, a smaller impact is likely to be the optimum (incursion of less than 15% of the natural cross section is often seen as a reasonable objective). Consider modelling the dynamic effect of the new structure.
- The physical disturbance to humans, migratory fish, birds and other ecosystems consider the effects of noise, light or chemical pollution. The client or planning authority may legitimately choose to seek environmental gain out of the project – new or improved facilities, larger and more diverse areas of habitat.

5.7.2 AESTHETICS

By its very nature, aesthetics is very subjective. Perhaps any system of classification could be under three broad headings:

- Poor or negative impact,
- Average or acceptable,
- Good or with added value.

For any major structure, we would recommend that an artistic impression should be commissioned to create a "vision" of the possible options. These artistic impressions will have many purposes including:

- Evaluation of options and optimising the preferred solution,
- Satisfying the expectations of client, stakeholders or the planning authority,
- Used as a visual and conceptual guide for the design team.

It is often wise to include structural and landscape architects as part of the design team.

Installations in urban sites or sites visited by a large number of people for recreation (sailing, walking, cycling, bird watching, etc.) may warrant closer attention to aesthetics than installations rarely seen by others.

5.8 COST (Construction, Maintenance and Operation)

Global cost for construction of a navigation weir is related to the site's physical constraints (geology, hydraulics, sediments science, aesthetics, etc.) and to the adopted weir type (flap gates, sills, etc.). Fig. 5.2 shows the different steps of a weir project including Conception, Design, Construction, and Operation and Maintenance.

But to obtain a real estimation, the operation and the maintenance cost should also be taken into account, these costs depend on the expected safety level. That is what is called "**global cost".**

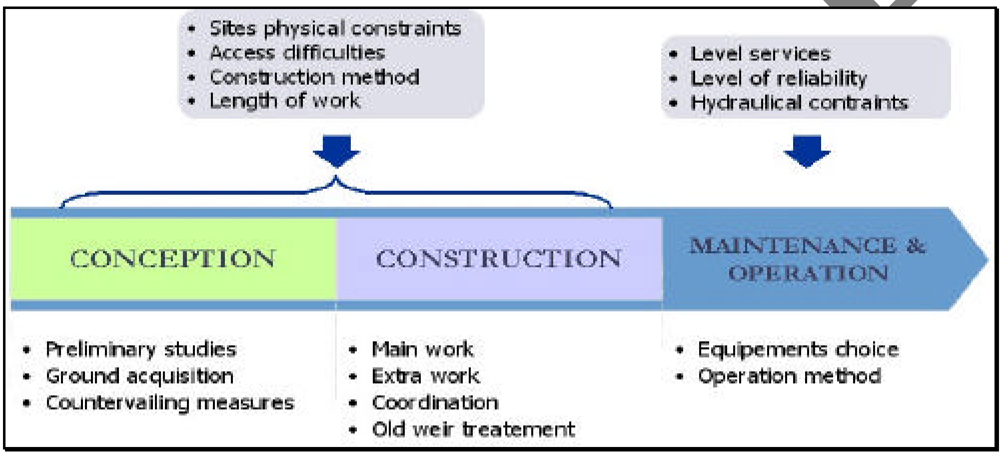


Fig. 5.2: Steps of a weir project (Conception-Design, Construction, and Operation and Maintenance)

6. DESIGN AND ASSESSMENT TOOLS

This section presents design and assessment tools currently used in standard practice for the design of movable weirs. Also, new trends in the use of advanced analysis are introduced.

The section is based on a questionnaire sent to about 20 design companies in about 12 countries (see Table 6.1). About half on these organisations (5 publics and 6 privates) replied (Belgium, Czech Rep., Germany, Japan, the Netherlands, UK, USA).

The list of companies/organisations, questionnaire and the answers received from survey participants, are available on the CD's Directory /Annex Section 6/.

The questionnaire focuses on the standard design tools used nowadays by engineers in the current practice of designing movable weirs and barriers. It also surveys the engineer's needs for specific and advanced tools taking into account, the design requirements that become more and more demanding (economic, technical, and environmental aspects).

In the following sub-sections, the design tools are categorized according to the different technical problems that an engineer faces during the design of a movable weir/barrier:

(1) CAD software for project drawing and plans,
(2) EARLY DESIGN tools including optimisation capability,
(3) HYDRAULIC: Flow pattern and discharge assessment,
(4) PHYSICAL MODELS in laboratories,
(5) LOADS assessment including dynamic water pressure, wind, wave, tide, snow, ice, etc.,
(6) Strength assessment of STEEL structures,
(7) Strength assessment of CONCRETE structures,
(8) Strength assessment of FOUNDATIONS,
(9) Static and dynamic FLOATING STABILITY assessment,
(10) FINANCIAL assessment,
(11) Other specific tools and software (RISK assessment, ENVIRONMENTAL assessment, GIS, etc.).

Tools, specificities and user requirements are discussed in relation with the tool purposes. For each technical problem (see points (1) to (11) above), the WG proposes a list of relevant tools with, if possible, recommendations and reference to previous experiences (with links to project reviews). According to the design stage (preliminary design stage, detailed design stage) specific problems with their associated assessment tools are discussed like structure optimization, cost assessment, nonlinear behaviour, large deflection, shock and impact, etc.

Some tool specificities are briefly presented/described with reference to annexes and/or web sites (when available). General-purpose tools like commercial finite element packages are considered as well as specialized tools, which are specific for particular applications/problems.

7. PREFABRICATION TECHNIQUES

7.1 DESCRIPTION

Flood control projects have traditionally been constructed in cofferdams. This allows traditional construction methods and equipment as well as conventional quality control inspections and measures to be used. The cost of this method is high; it requires the temporary construction of a large cofferdam that serves no final purpose and needs to be removed after construction. There is the risk of overtopping and potential damage to work in progress as well as delays to construction for demobilization, flooding, cleanup and start up efforts.

Prefabrication has long been used on flood control projects for various gate components. Typically the steel gates themselves and their operating components are fabricated offsite and then placed by crane. If the gates are too large to be handled in one piece, they may be brought to the site in sections and assembled in place.

Improvements in technology and engineering knowledge have increased the viability of prefabrication. It is now possible to completely construct hydraulic structures without a cofferdam. The subgrade and foundation can be prepared "in-the-wet" by floating construction equipment that prepares the river bottom and supporting structures from the surface. Templates or guide structures that extend above the water surface can provide great accuracy in placement.

Shells for the substructure and/or superstructure are constructed offsite, transported via a navigable waterway to the site and set in place, see Fig. 7.1.

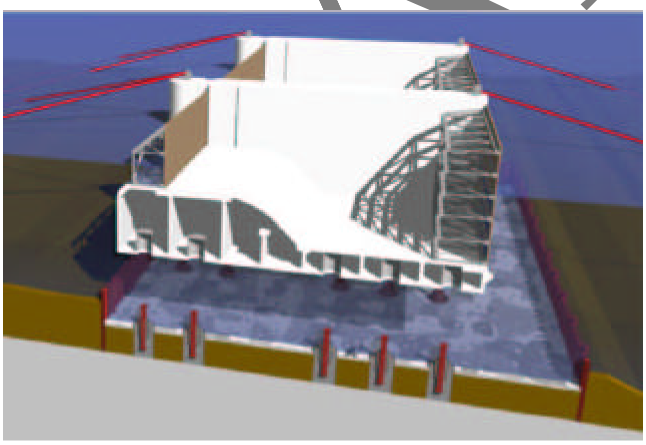


Fig. 7.1: Braddock Lock & Dam Tainter Gate Bay Float in Segment (prefabricated civil works)

The structure is then filled with concrete to complete the structure and join it to the foundation. If necessary, the gate openings can be closed with bulkheads and dewatered for installation and final adjustment of the gates. It may also be possible to preinstall the gates in the concrete shell prior to their transport and set-down.

A prefabricated gate foundation structure is typically built as a shell structure fabricated of reinforced concrete. Steel or aluminium plate can also serve this purpose but are not as common. The shell is designed to provide a finished surface for the final structure and to provide a "stay-in-place" form for the in-fill concrete that is added at the project site. The shell may also function as its own floating vessel, allowing the shell to be floated and towed to the site. Temporary bulkheads can be installed in openings at the periphery of the shell to allow an otherwise open structure to float.

As an alternative, the prefabricated units may be designed to be lifted into place by large capacity floating cranes. These units can be fabricated adjacent to the final site, launched via a marine railway or skidway and picked up near shore by the crane, carried to their final destination, and lowered into place. If the units are not too large, they can be fabricated further away and transported to the site by barge.

In-the-Wet construction allows rapid completion of construction, minimizes disruption to existing river traffic, and has less environmental impact than conventional techniques.

Flood control structure site locations are typically chosen as a place where hydraulics, topography and geologic requirements can best be met. When selecting a site, the availability of good roads, access to a trained labor force, and availability of materials and equipment are not necessarily part of the selection process, but they are important to the construction of the structure. Prefabrication allows a significant portion of the gate structure to be fabricated in the dry, at a more advantageous site and greatly reduces the area of the site that is involved in construction. This may allow the consideration of a larger number of potential flood control structure sites.

8. CODES, RULES and STANDARDS

8.1 APPLICATION OF NEW STANDARDS TO HYDRAULIC STRUCTURES

8.1.1 THE LIMIT STATES DESIGN AND THE SEMI-PROBABILISTIC FORMAT

The development of new standards (like Eurocodes) based on limit states and partial factors format, has been focusing on the need to express harmonized design standards in practical terms. So far, hydraulic structures have been mainly designed using different rules according to the relevant part of the structure (structural vs foundation design) that leads to tricky situations when different formats are used simultaneously.

On the other hand, several actions [static and dynamic water pressure, waves, currents, … as well as actions due to vessels (berthing, mooring) and to port activities (live loads, cranes, equipments…)] fall out of the scope of existing standards, which are mostly devoted to buildings and bridges (wind, snow, exploitation loads, traffic actions). To overcome this problem, some aspects of the semi probabilistic format were developed, by unifying the «*source factors*» and by diversifying the «*model factors*». The most important issues to be addressed when developing a limit states verification format are then: partial factors, characteristic values for actions with emphasis on water actions, assessment of safety level, and calibration procedures.

In Europe, some aspects of the Eurocodes' format were developed by unifying the «*source factors*» and by diversifying the «*model factors*». The «*source factors*» are related to actions, materials and resistances; they allow only for the intrinsic uncertainty on parameters and their values are mainly derived from existing codes or regulations. The «*model factors*» are introduced in the limit state function at the last stage in the verification process and must be calibrated in order to fit with traditional design rules.

In France, this has led to the publication of «*Guidelines for the limit state design of harbour and waterways structures*» such "ROSA 2000" based on the Eurocodes' format (CD's Directory /B2 ../).

8.1.2 A HARMONISED DESIGN PROCEDURE

In Europe, a major development began at the end of the 1970s, with the progressive substitution of the traditional «allowable stress» methods by semi probabilistic methods in the rules for checking structural safety.

The considered limit states are:

- Ultimate limit states (ULS) which, if exceeded, would result in the destruction of the structure through loss of static equilibrium, mechanical strength, shape stability, etc.; ULS are those phenomena whose occurrences have so dramatic consequences that it is economically consistent to prevent them by severe predetermined safety margins.
- Serviceability limit states (SLS) which, if exceeded, would result in a malfunction that would jeopardise the intended use of the structure; SLS are those phenomena whose occurrences have only limited consequences so that it is economically consistent to assess less severe safety margins.

In Eurocodes, formats are used depending to the limit states and the nature of the basic variables. To do that, partial factors are divided into:

- «*Source factors*», noted γ_f, γ_M and γ_R, which apply to the basic variables, like ground properties, structural loads, material properties, etc.
- A unique γ_d «*model factor*» (for the sake of simplicity). This "*model factor*" is supposed to be located on the left side of the limit state condition, i.e. increasing the action effect.

The general expression of a limit state condition with partial factors, for ultimate limit states, reads:

$$\gamma_d . E(\Sigma\gamma_f . F_k) \leq R[\Sigma(X_k / \gamma_M)] \qquad (8.1)$$

where:

- F_k are loads, R is the design value of the resistance and X is a material parameter (soil, concrete, steel …).
- E is a function of several parameters (geometry, loads....). It symbolizes the model equation (can be a simple analytic model to a complex 3D FE analysis), which for instance, gives the stress at a specified location.

In practice, it means for instance, that the usual Eurocode load factor for permanent actions (1.35) is the product of a source factor (γ_f = 1.20) and a model factor (γ_d = 1.125). The same holds for the 1.50 Eurocode factor used for variable actions which is the product of γ_f = 1.33 and γ_d = 1.125.

9. CONCLUSIONS & RECOMMENDATIONS

The WG has investigated a variety of projects and concludes that much knowledge and information particularly relevant to the design of movable weirs is available, but not being taken advantage of. We hope that this report will enable designers of future projects to take advantage of that knowledge and information, leading to improvements in design and economies in construction.

As it was stated that the '*design of movable river weirs is a conservative world*', the WG recommends:

- About Innovation
  The Public Administrations, who are usually the weir owners and managers, should leave more room for innovation and new concepts.

- About Prefabrication and Standardisation
  Prefabrication usage that closely relates to standardisation should be investigated, as it is a source of savings, fast construction, and friendly environment construction modes.

- About Temporary Closure Devices
  Temporary closure devices and maintenance bulkheads must be considered as a key issue of an efficient design.

- About Design Procedure and Multidisciplinary team
  It is now time to integrate the traditional weir design procedures with risk assessment, maintenance and control, codes and standards (Eurocodes), and design concept (limit states and partial safety factors). Such integration requires a multidisciplinary team composed of engineers, economist, biologist, social analyst, etc.
  Limit state concepts and semi-probabilistic approaches (as included in the EUROCODES) should be commonly used in the future.

- About Computational Tools
  We should promote the development and use of specific computational tools for preliminary design. Advanced analysis can now be performed at the early design stage to show the feasibility of new innovative concepts. Optimisation can also be performed at the early stage, as it can induce large savings. Delaying will reduce the potential benefits.

- About Gate type selection
  Gate selection is an important stage in a barrier or weir project. The operational, financial, and other consequences of this selection are often more severe than are the detailed engineering. It is, therefore, advisable to give thorough consideration to the gate type selection.

- About Multi-criteria Analysis
  Previous experiences of skilled engineers may be used, but cannot replace a brainstorm meeting to get innovative concepts and then a fair multi-criteria assessment.

  Recommendations about multi-criteria assessment are:
  - It is advised to let the criteria and their weighting factors be determined by a team representing the project initiator (local authorities, other parties involved) – and the actual rating by a multidisciplinary team of professionals. Both teams should act independently.
  - Effort should be made to get a clear, well-balanced inventory of all criteria significant for a particular project. Clusters of criteria may be considered. In addition, it should be advised to keep the number of gate types under investigation small, e.g. not larger than 4 to 6.
  - Qualitative assessments are procedurally simple and fast – but, on the other hand, quite arbitrary and not very transparent. Quantitative assessments require more effort and time, but are less arbitrary and more transparent. The assessments based on cost analyses are probably the best quantifiable approaches, but a more universal assessment method is the performance rating with weighting factors for different criteria. The performance rating method is not free of arbitrariness, but it is more transparent than the qualitative methods; and better balanced than the methods based on costs analyses.

- About Maintenance and Standardisation
  Maintenance is one on the major hidden issues of a weir design. Maintenance must be considered at the early design stage in order to reach a high efficiency/cost ratio and a high operational standard. Considering maintenance at the design stage may incur higher investment costs but, for sure, will reduce the 30-50 years life-cycle global operational cost.

- About Floating Structures
  Designing movable a structure as floating structures should be used more as it usually leads to simple, cheaper, and more reliable structures. Floating structures require the use of specialist and specific tools to assess floating stability at any stage. Floatability can also be used as a construction mode (see prefabrication techniques).

- About Control of Operation
  The philosophy "Keep it Simple" is always good, but not always realisable! There are examples of very simple flood defence structures that work well, but need a lot of manual input. There are also some very sophisticated structures that operate entirely by automation. The real question lies in the reliability of the system and the consequences of failure. It is recommended that all critical elements of the control system be duplicated and that the power supply and drives be backed up to some extent.

- About Risk Based Design:
  Risk analysis is now an accessible tool for the design of weirs and barriers. It is particularly useful when failure may induce important damages to nature, cities, and the human lives.

  Benefits of using a risk-based design are:
  - Evaluating margins of safety more realistically than traditional (deterministic) safety criteria,
  - The possibility to achieve economic benefits,
  - Comparing a wide variety of options and enable the risks due to flood defence to be compared with the risks due to other natural and man-induced hazards,
  - Consider not just the likelihood of high water levels against a defence (barriers, dikes, etc.), but also the likelihood of defence failure and the degree of harm resulting to people/property, etc. behind the defences.

- About Environmental Impact and Aesthetics
  It is recommended that clients, designers, and planning authorities be mindful of the "*whole life cycle*" impact of their projects.
  Similarly, it is important to consider the "*whole environmental footprint*" of the project and not just factors relevant to the site of construction and operation.

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VNF (Voies Navigables de France) : http://www.vnf.fr/

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The International Canal Monuments List : http://www.icomos.org/studies/canals2a.htm

ICOLD-CIGB, Technical Dictionary on Dams and Glossary appended, International Commission of Large Dam: www.icold-cigb.org

U.S Army Corps of Engineers: http://chl.wes.army.mil/library/publications/

Seacor environmental products http://www.fossenv.com/worldwide/products/boom/security/index.html

Whisper Wave http://www.whisprwave.com/port.htm

APPENDIX A: NUMERICAL TOOLS FOR WEIR AND BARRIER DESIGN

Appendix of Section 6 “DESIGN AND ASSESSMENT TOOLS”

The following software list was established based on a survey made by the WG (Section 6). This list is obviously not a comprehensive list. It is more a quantitative list that gives a relevant sample of tools used in 2004 by designers, contractors and civil engineering companies in the field of movable weirs and storm surge barriers.

Note that physical modelling is also another option and it could be more cost effective for some aspects.

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Movable bridges	Offshore equipement
Roro brigdes ,gangway	Industrial equipement

Tel : +33 2-41-45-70-00 Fax : +33 2-41-45-71-45
Email : isming@ism-engineering.com
Z.A. de Lanserre – 15 rue de la Fuye
49610 JUIGNE SUR LOIRE - FRANCE

ISM References are on the CD at:
/A3- Sponsor References/6-ISM

7. Dyrhoff as

www.dyrhoff.no

- **Dyrhoff is one of the largest suppliers of pneumatically operated spillway gates and inflatable rubber dams**
- **Dyrhoff represents Obermeyer Hydro Inc., Sumitomo Electric Industries, Ltd. and other rubber dam manufacturers**
- **Dyrhoff offers supply only or turnkey packages.**

Tel : +47 624 28444 Fax : +47 624 28445
Contact: Mr Don Mason Email: don@dyrhoff.no
Industrigaten 14, 2406 Elverum, Norway

OBERMEYER References are on the CD at:
/A3- Sponsor References/7-OBERMEYER

8. RUTTEN s.a

ELECTROMECANIQUE - TURBINES

→ Générateurs Hydro-Electriques (Hydro-Electricity, Hydraulic Turbines)

Produits:

→ **Hydraulienne au fil de l'eau captant l'énergie cinétique des rivières. Puissance: 15 à 500 kVA. Adapté à l'alimentation autonome des villes en Afrique. En Europe, le Rhône, le Rhin et le Danube conviennent pour ce type d'installations.**

→ **Turbine pour basses chutes de 2 à 4 m, sans génie civil, pour des débits allant de 10 à 120 m³/sec. et pour des puissances jusqu'à 2,8 MW.**

Email & contact: Jean et Leon RUTTEN (rutten@skynet.be)
Parc Industriel des Hauts-Sarts ,Première Av. 123-125, 4040 Herstal, Belgique (Belgium)
Tel : +32-4-264 85 75 Fax : +32-4-264 85 89

Références de RUTTEN s.a. sur le CD-Rom, voir:
/A3- Sponsor References/8-RUTTEN

9. SCALDIS SALVAGE & MARINE CONTRACTORS N.V.

www.scaldis-smc.com

- Heavy Lift contracting for : civil construction, offshore construction, tunnel works, installations of platforms, windfarms.
- Removing and dismantling of offshore structures, platforms, bridges, ……
- Salvage and wreck removals

Tel : +32-3-541-69-55 ; Fax : +32-3-541-81-93
Contact & email: M. Voorhuis <mail@scaldis-smc.com>

SCALDIS References are on the CD at:
/A3- Sponsor References/9-SCALDIS

10. SVKS

TEMPORARY COOPERATION

Partners :

SVKS was created to design and build a Storm Surge Barrier near Antwerp on the river Scheldt (Belgium).
SVKS combines the Belgian knowledge and expertise in

- **Barrier, Hydraulic and Civil Design: Technum and IMDC consulting engineers**
- **Hydraulic Constructions: Van Laere, Visser&Smit Hanab**
- **Dredging Works: Dredging International**

Tel : +32-3-270-92-51 Fax : +32-3-270-92-68
Email & contact: F. Zwaenepoel <info@imdc.be>

Company References are on the CD at:
/A3- Sponsor References/10-SVKS

11. VICTOR BUYCK STEEL CONSTRUCTION

www.groupbuyck.com

Market Leader in steel bridges, steel components of locks, steel high and low rise buildings and steel industrial buildings.

Workshops in Belgium (Europe) and Malaysia (Asia).

Tel : +32-9-376-22-11 Fax : +32-9-376-22-00
Email & contact: manuel.buyck@buyck.be

Victor BUYCK References are on the CD at:
/A3- Sponsor References/11-BUYCK