InCom Working Group 26

Design of Movable Weirs and Storm Surge Barriers

Final Report Version 6.7
1st August 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).
- Technical background required to perform hydraulic and flow analysis of various gate types (Section 5.2)
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- Survey of the temporary closure systems used for inspection and maintenance (Section 5.5).
- State-of-the-art on 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 aspects (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 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 Lock 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