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Hydraulic Structures - ISHS2018 in Perspective

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ABSTRACT

Hydraulic structures continue to play a significant role in society's diverse and challenging dependence on water. Hydraulic structures influence water conveyance, flood protection, energy production, and environmental and ecological impacts. The 7th IAHR International Symposium on Hydraulic Structures (ISHS2018) provided a venue for exchanging knowledge and discussing key issues related to hydraulic structure research, performance, operations, maintenance, and community implications. This symposium series maintains a rich tradition of exploring advancements in the maximizing the benefits of hydraulic structure elements while working to reduce the associated challenges. Presentations and discussions were held on advanced tools and analysis, applications and case studies, and novel approaches to developing and implementing more effective, environmentally sound, and robust solutions. The goal of these ISHS2018 proceedings is to provide applicable state-of-the-art knowledge for use in hydraulic structure analysis and design by the engineering profession.

Keywords: *Hydraulic structures, hydraulics, society demands, engineering challenges*

1. Symposum Organization

The 7th International Symposium on Hydraulic Structures was held the 14th-18th of May, 2018 in the SuperC building in Aachen.. A total of 108 individuals attended ISHS2018 representing 27 countries and 5 continents. Organization efforts were handled by two committees: the Local Organizing Committee and the International Scientific Committee. The Local Organizing Committee consisted of 4 individuals (see following page) who worked closely with the Hydraulic Structures Technical Committee of the International Association of Hydro-Environmental Engineering & Research (IAHR) to organize this event. The International Scientific Committee oversaw the technical program and publication of the proceedings. ISHS2018 took place over 3 days and was preceded by two additional technical events (a short course on Open Channel Flow Basics and a workshop on nonlinear weir design). The Symposium included two days of technical presentations and the concluding event was a technical field tour on the third day. Details are discussed in the following sections.

Local Organizing Committee ISHS2018

Daniel Bung
Chair

Mario Oertel
Vice Chair

Sebastien Erpicum
Member

Daniel Valero
Member

1.1. Short Course on Basics of Open Channel Flow

Professor Hubert Chanson provided a short course on the basic principles of open channel hydraulics which was attended by 28 individuals from 8 different countries representing: Africa, America, Europe and Asia.

The course offered an introduction to the hydraulics of open channel flows. The material was designed for undergraduate and postgraduate students in civil, environmental and hydraulic engineering, as well as young professionals and early-career researchers. It was assumed that the participants have had an introductory course in fluid mechanics and that they are familiar with the basic principles of fluid mechanics: continuity, momentum, energy and Bernoulli principles.

The course developed the basic principles of fluid mechanics with applications to open channels. Open channel flow calculations are more complicated than pipe flow calculations because the location of the free-surface is often unknown a priori (i.e. beforehand). The workshop was structured as follows:

1. Introduction to open channel flows
2. Basic principles of open channel flows
3. Application of the Bernoulli principle to open channel flows: short and smooth transitions
4. Application of the momentum principle to open channel flows: hydraulic jumps, flow resistance, uniform equilibrium flow
5. Gradually-varied steady open channel flow: hydraulic engineering of long channels and backwater calculations

1.2. Workshop on Hydraulics of Nonlinear Weir Spillways

A full-day workshop on the hydraulics of nonlinear weir spillways was organized and presented by Sebastien Erpicum, Brian Crookston, Blake Tullis, and Frederic Laugier (see Fig. 1). The room capacity was fully completed with 20 individuals attending this specialty workshop, which included summaries on labyrinth and piano key weir research, design techniques, implementation overviews, and challenge. Attendees were provided with a 120-page binder that included instructor slides (in color) and key references (provided in black and white).

Figure 1. Workshop session. Left: Presenting, Dr. Erpicum. Right: Laugier, Prof. Dr. Tullis, Prof. Dr. Crookston (from left to right).

1.3. Technical Presentations

Technical presentations (Fig. 2) were given Wednesday and Thursday, with two parallel tracks. Presentations were approximately 20 minutes in duration, including questions at the end. A total of 108 individuals attended this portion of the technical program. 14 technical sessions were held, each with one moderator. Session moderators included:

Moderators ISHS2018	
Prof. Dr. Fabian Bombardelli	Prof. Dr. Mario Oertel
Prof. Dr. Hubert Chanson	Prof. Dr. Stefano Pagliara
Prof. Dr. Brian Crookston	Dr. Michele Palermo
Prof. Dr. Tom de Mulder	Prof. Dr. Artur Radecki-Pawlik
Dr. Sébastien Erpicum	Prof. Dr. Anton Schleiss
Dr. Sherry Hunt	Dr. Carsten Thorenz
Dr. Sean Mulligan	Prof. Dr. Blake Tullis

Three invited **keynote lectures** were given:

- **Paul Schweiger**, Gannet Fleming Engineering (manager of dams hydraulics section) – Topic: Lesson-to-be-Learned from the Oroville Dam Spillway Incident.
- **Prof. Dr. Robert Boes**, ETH Zürich – Topic: Multi-phase flow at hydraulic structures: water-sediment, air-water, and water-structure-fish interaction.
- **Prof. Dr. Andreas Schmidt**, Federal Waterways Engineering and Research Institute (BAW-Director) – Topic: Modelling in Waterways Engineering-Expectations and Challenges.

Prof. Dr. Thanos Papanicolaou (University of Tennessee USA), Editor of the Journal of Hydraulic Engineering, gave a special lunch-time presentation on the state of the Journal presenting the latest news on the research publications output and performance indicators. Additionally, a Special Issue based on some outstanding works of ISHS2018 was announced.

Figure 2. From left to right: technical session from Moderator's desk; Paul Schweiger addressing Keynote 1; and Symposium dinner reception.

1.4. Field Tour

The final day of the symposium included a technical tour of Eupen Dam and Water Treatment Plant (Belgium) and the Coo Pump-Storage Plant (Belgium) (see Fig. 3). Approximately 60 individuals attended the tour. Eupen dam and water treatment plant, which includes nanofiltration, have been an important source of clean drinking water in the region since 1951. The Coo pump-storage plant was built between 1971 and 1979 to supports the Tihange nuclear power plant located next to river Meuse. It has a generation capacity of 1,164 MW with 6 pump-turbine groups located in an underground cavern. Two upper reservoirs provide a combined storage capacity of 8.5 million m^3 and are located 279 m above the lower reservoir. The plant is operated by ENGIE company and is a key component of the overall power production system in which intermittent renewable energy sources play a growing part.

Figure 3. Group picture in front of the Eupen dam alternating stepped spillway.

1.5. Awards

ISHS 2018 was the inaugural year of the Philip H. Burgi Best Paper Award, awarded to the best paper of the Symposium. The ISHS2018 Philip H. Burgi Best Paper award was giving to Dr. Svenja Kemper. Schnabel Engineering (USA) donated an iPad to accompany the award.

The program also included a welcome reception and a closing ceremony and dinner. Announcement of the Best Paper award winner was part of the closing dinner program.

2. Symposium Proceedings

2.1. Peer Review Process

All papers published in the Proceedings and have been thoroughly peer-reviewed for technical quality and presented at ISHS2018. The Proceedings were published by Utah State University and are available open access at http://digitalcommons.usu.edu/ishs/2018/. Each manuscript includes the ISBN of the Proceedings as well individual direct object identifiers (DOI). Each manuscript is indexed by Scopus and Compendex and available to users through the USU digital commons portal pursuant to a Creative Commons Attribution-NonCommercial CC BY 4.0 license. The ISHS2018 Scientific Committee was comprised of the following individuals:

International Scientific Committee ISHS2018

Chair: Blake P. Tullis, Vice-Chair: Daniel B. Bung

1	Markus Aufleger	18	Helge Fuchs	35	Mario Oertel
2	Antonio Amador	19	Rafael García- Bartual	36	Stefano Pagliara
3	Robert M. Boes	20	Nils Goseberg	37	Michele Palermo
4	Fabian Bombardelli	21	Carlo Gualtieri	38	Michael Pfister
5	Benoit Blancher	22	Sherry Hunt	39	Artur Radecki- Pawlik
6	Duncan Borman	23	Robert Janssen	40	Anton Schleiss
7	Didier Bousmar	24	Svenja Kemper	41	Andreas Schlenkhoff
8	José María Carrillo	25	Matthias Kramer	42	Lukas Schmocker
9	Rita F. de Carvalho	26	Joseph H.W. Lee	43	Frank Seidel
10	Luís Castillo	27	Eric Lesleighter	44	Sandra Soarez- Frazao
11	Oscar Castro- Orgaz	28	Amparo López- Jiménez	45	Vallam Sundar
12	Giovanni de Cesare	29	Arturo Marcano	46	Carsten Thorzen
13	Hubert Chanson	30	Jorge Matos	47	Peter Troch
14	Benjamin Dewals	31	Tom de Mulder	48	Daniel Valero
15	Sébastien Erpicum	32	Sean Mulligan	49	Roman Weichert
16	Brian Crookston	33	Frederic Murzyn	50	Youichi Yasuda
17	Stefan Felder	34	Ioan Nistor	51	Jinhai Zheng

Under direction of the co-chairs, a formal and rigorous blind peer-review was conducted for each submitted manuscript by reviewers made up of the ISHS2018 International Scientific Committee. The International Scientific Committee was comprised of international experts in field of hydraulic structures.
The Call for Papers was issued in 2017; in response, 146 abstracts were received by 1 September 2017. All abstracts were reviewed; of those accepted, 89 full draft manuscripts were received. All received manuscripts were reviewed by a minimum of two reviewers. Special acknowledgements to Dr. Blake Tullis and Dr. Daniel Bung for their contributions to this effort.

Reviews were uploaded into the USU ISHS2018 repository through digital commons and made available to authors. The authors were sent instructions for access and requested to revise their manuscripts in accordance to the reviewers; comments and recommendations by the Scientific Committee Chair and Vice Chair. The final number of revised papers accepted for presentation was 77. However, one manuscript failed to be presented in Aachen during ISHS 2018 technical sessions; a requirement for publication in the Proceedings. As a result, only 76 manuscripts have been published and included in the Proceedings. In addition, extended abstracts by the three invited keynote lecturers have been included with the full manuscripts, to document their participation and important contribution to ISHS 2018. These 3 individuals were:

Mr. Paul Schweiger, Keynote Speaker
Prof. Dr. Robert M. Boes – Keynote Speaker
Prof. Dr. Andreas Schmidt – Keynote Speaker

The publication of the proceedings marked a significant contribution of this event, involving about 214 authors from countries and 5 continents. Furthermore, the event website (www.ishs2018.fh-aachen.de) to date, has received approximately 10,000 page views.

2.2. Proceedings Reference

The Proceedings were published by Utah State University and is available open access at http://digitalcommons.usu.edu/ishs/2018/. The full bibliographic reference for the ISHS2018 symposium proceedings is:

Tullis, B.P. and Bung, D.B. (Eds.) (2018). *Hydraulic Structures Symposium.* 7th IAHR International Symposium on Hydraulic Structures, Aachen, Germany, 14-18 May. (pp. i-731). ISBN 978-0-692-13277-7.

Each paper of the proceedings includes a cover sheet that includes the correct manuscript reference, such as:

Tullis B.P. and Bung, D.B. (2016). Hydraulic Structures Symposium-ISHS2018 in Perspective. In B.P. Tullis and D.B. Bung (Eds.), Hydraulic Structures Symposium. 7th IAHR International Symposium on Hydraulic Structures, Aachen, Germany, 14-18 June (pp. i-viii). doi: 10.15142/T3WH2B
(ISBN 978-0-692-13277-7).

3. Acknowledgements

ISHS2018 would not have been possible without the generous and active involvement of the members of the local organizing committee, the international scientific committee, and student volunteers from the Aachen University of Applied Science. To keynote speakers, workshop instructors, all authors, presenters, and participants: thank you for your participation, support, and enthusiasm. Logistical support for the Proceedings was provided by Becky Thoms, head of digital initiatives at Utah State University – thank you for your patience and many efforts! Also, we wish to express appreciation to Breanne Harris, Bayli Luebke, Katie Myler, Danni Noyes, and Jessi Spackman of Utah State University for their assistance with technical and English grammar editing.

4. Organizing Institutions, Sponsors, and Supporting Organizations

4.1. Organizing Institutions

IAHR AIRH International Association for Hydro-Environment Engineering and Research
Supported by Spain Water and IWHR, China

4.2. Supporting Organizations

The following organizations (listed alphabetically) provided support and assistance for ISHS2018.

FH Aachen University of Applied Sciences
FH Lübeck University of Applied Sciences
Université de Liège
University of Queensland
Utah State University
Utah Water Research Laboratory

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Design Features of the Upcoming Coastal and Ocean Basin in Ostend, Belgium, for Coastal and Offshore Engineering Applications

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Abstract: *The new Coastal and Ocean Basin (COB) located at the Greenbridge Science Park in Ostend, Belgium is under construction since February 2017. The laboratory will provide a versatile facility that will make a wide range of physical modelling studies possible, including the ability to generate waves in combination with currents and wind at a wide range of model scales. The facility is serving the needs in Flanders, Belgium, in the fields of mainly offshore renewable energy and coastal engineering. The COB will allow users to conduct tests for coastal and offshore engineering research and commercial projects. The basin will have state-of-the-art generating and absorbing wavemakers, a current generation system, and a wind generator. It will be possible to generate waves and currents in the same, opposite and oblique directions. The basin is expected to be operational in 2019. This paper presents an overview of the basin's capabilities, the ongoing work, and selected results from the design of the COB.*

Keywords: *Coastal and Ocean Basin (COB), wave and current generation techniques, marine and offshore energy basin, wave and tidal energy, wave-current interaction.*

1. Introduction

A new Coastal and Ocean Basin (abbreviated as COB, see also at http://COB.ugent.be), Figure 1 showing an artist impression, is being constructed at the municipality of Ostend in Belgium, within the context of the Gen4Wave project. The COB aims to satisfy the demand by the academic sector, the government, and private companies developing coastal and offshore technology. The facility will cover a wide range of needs while keeping the lowest possible operating costs, which has led to the adoption of several unique solutions both in the management of the project and in the engineering approach.

Scientific research in the fields of coastal and offshore engineering, like many other engineering domains, has evolved into a so-called integrated research methodology, combining both numerical and physical scale modelling. In this context, the scarcity and limitations of existing testing infrastructure for maritime research and development calls for further investment in this sector. As part of the requirements for the funding of the Gen4Wave project, the interest in the project had to be demonstrated by both the private and the academic sector. This task has been successfully achieved, as the project received ample actions of "expression of interest" for both the commercial and the academic use of the facility.

These actions ensure the complete allocation of available time windows for use of the facility by the private and the academic sectors during the initial phase of operation.

The three partners within the COB project, i.e. Ghent University (UGent), University of Leuven (KU Leuven), and Flanders Hydraulics Research (FHR), have a longstanding research record in projects involving wave propagation, coastal processes, coastal structures and marine renewable energy. Swift access to a large-scale facility with multi-directional waves, currents and wind, will enable breakthrough experimental research in the fields of coastal engineering and marine renewable energy.

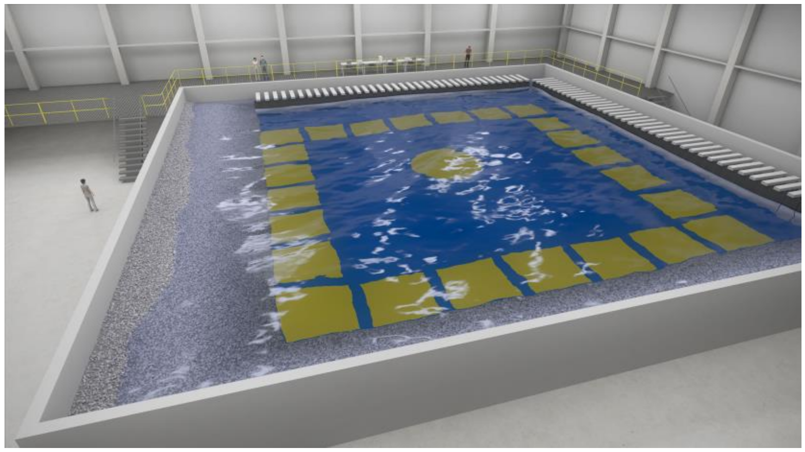

Figure 1. Artist impression of the Coastal and Ocean Basin.

Flanders has a long tradition in coastal engineering supported by the experimental infrastructures of UGent (wave flumes) and of the FHR (wave flumes and basin). However, the dimensions of the existing FHR wave basin (17.5 m ×12.2 m × 0.45 m) are limited and only very small-scale models are studied, focusing mainly on coastal engineering applications. Therefore, the COB basin covers the infrastructure gap in Flanders which answers the high demand for large(r)-scale and higher complexity wave, currents and wind loading conditions for coastal engineering, offshore and wave/tidal energy applications.

In the field of renewable energies, we aim at a detailed understanding of the optimal geometrical lay-outs of wave energy converter (WEC) farms under realistic 3D wave-current conditions, as well as of the interactions between the WECs of the farms. This comprises the establishment of a generic dataset to validate the recently developed high precision numerical models (Folley et al. 2013, Folley 2016, Troch and Stratigaki 2016) used to simulate WEC farm effects. This new dataset will be realised at the COB within an upcoming WEC farm research project, designed to follow-up the existing 'WECwakes' project (Stratigaki et al. 2014, Stratigaki et al. 2015, Stratigaki 2014). Furthermore, experimental research aiming at numerical model validation of wave slamming on complex floating objects such as (but not limited to) WECs, as well as on WEC mooring effects, is planned.

In the field of coastal engineering fundamental questions on the impact loading of structures due to combined waves and currents, and the consequent structural response, still remain unsolved. A few examples of these scientific matters under (combined) wave and/or current conditions are: (i) the prediction of wave overtopping at harbour quay walls, (ii) the interaction of overtopping flows with storm surge walls, (iii) the prediction of damage of scour protections for monopile wind turbines, and (iv) the impact of (seagrass or salt marsh) vegetation on the incident waves and /or currents as well as on the bottom erosion parameters. These research questions will be tackled at the COB, amongst others, and will allow the realisation of state-of-the-art coastal and offshore engineering research in Flanders on a high international level. To this end, swift access to a large-scale facility with multi-directional wave and current generation is indispensable. Finally, the COB will enable further studies of the role of wave-current and wave-wave interactions on the excitation of freak waves. This research line has been seriously hampered by the scarcity of 3D wave basins capable of generating high quality flows for wave-current interaction studies.

2. Background

As the project has gathered interest from both industry and academia, it received financial support by different organisations. UGent together with KU Leuven obtained financial support for the wave-current generation system by the Hercules Foundation in the amount of approximately 2.3 million Euros. UGent and KU Leuven provide complementary funds in the frame of this funding. The Hercules Foundation is a Flemish structural funding instrument for investment in large-scale infrastructure for fundamental and strategic research in several scientific disciplines, as part of the Research Foundation – Flanders (FWO).

The Gen4Wave project has made available the resources to acquire additional equipment required to make the COB fully operational. The Gen4Wave project is financed by the Flemish agency "Flanders Innovation &

Entrepreneurship" – VLAIO (in Dutch: Agentschap Innoveren & Ondernemen), which is providing approximately 3 million Euros for the initial investments and foresees 2 million Euros for the operational phase of the COB. The building and main infrastructure is provided by the Maritime Access Division of the Flemish Ministry of Mobility and Public Works. This includes the housing and the concrete framework of the wave basin.

2.1. Gen4Wave Project

The COB is part of the Gen4Wave action plan as a result of an initiative by the Flemish government which supports the innovative manufacturing industry in the field of renewables. The plan has been developed by UGent and Agoria Renewable Energy Club (AREC) upon request of Generaties, a working group with main target to position Flanders in the field of renewable energy production. This action plan came into existence as a result of activities led by the consortium of UGent (coordinator), KU Leuven and Flanders Hydraulics Research (FHR).

The increasingly huge demand for physical model testing, in combination with the limited capacity of existing infrastructure, has led to the actual need for testing facilities in Europe. Within the preparation for the COB research proposal, we further conducted an exhaustive study of the existing infrastructure in Europe. The first step was to identify the industry and research gaps in terms of new actual needs for testing facilities in Europe. Through this procedure, we aimed at identifying the position and profile of the COB next to other testing facilities in Europe regarding, at first instance, dimensions and capabilities. As a result, the Unique Selling Propositions (USPs) of the COB are:

- COB-dimensions allow all kinds of target applications for the industry and the academia at various scales, and most importantly at a realistic and acceptable cost.
- Ability to accurately reproduce (combined) loads of waves, current and wind.
- Powerful machinery able to generate significant loads of waves, current and wind.
- High load directionality, with currents and waves interacting at any desired directions relative to each other.

2.2. Synergy with the Towing Tank

Moreover, the COB project offers a unique opportunity to create a strong research synergy between the COB and the new towing tank, commissioned under a joint initiative between FHR and UGent. Both infrastructures (wave basin and towing tank) share the same housing facilities in the Flanders Maritime Laboratory at the Greenbridge Science Park location, just a few kilometres from the Ostend harbour.

2.3. Consortium

The consortium for the COB is composed by UGent, KU-Leuven and FHR. The following research groups participate from the Civil Engineering Department of UGent: (1) Coastal Engineering research group, (2) Maritime Technology Division, and (3) the research group of Mechanics of Materials and Structures. KU Leuven participates with the Hydraulics Laboratory. All the above groups will offer their specific expertise in the upcoming academic projects in the COB: coastal and offshore structures engineering, marine renewable energy, composite materials, slamming and deformation, maritime technology, wave-current and wave-wave interaction and sediment mechanics.

3. Design Basis

In this section, the specific elements which are part of the Coastal & Ocean Basin (COB) are reviewed in the context of the COB targeted functionality. This comprises the basin facilities (Section E), the infrastructure to generate loads (waves, currents and wind) and to adjust the water levels (Sections E - I), and the instrumentation techniques and data acquisition system (Sections J and K, respectively).

3.1. Location

The COB will be located at the Greenbridge Science Park close to the port of Ostend (Figure 2, top). Greenbridge covers about eighteen hectares and provides the necessary space and services for the planned COB wave basin, as well as for the development of future industrial activities. The Science Park also houses the so-called Greenbridge incubator which can be used by start-up companies that are associated to the wave basin to develop commercial activities thus having the opportunity to grow. The proximity to the port of Ostend is an advantage as the site is a strong renewable energy hub.

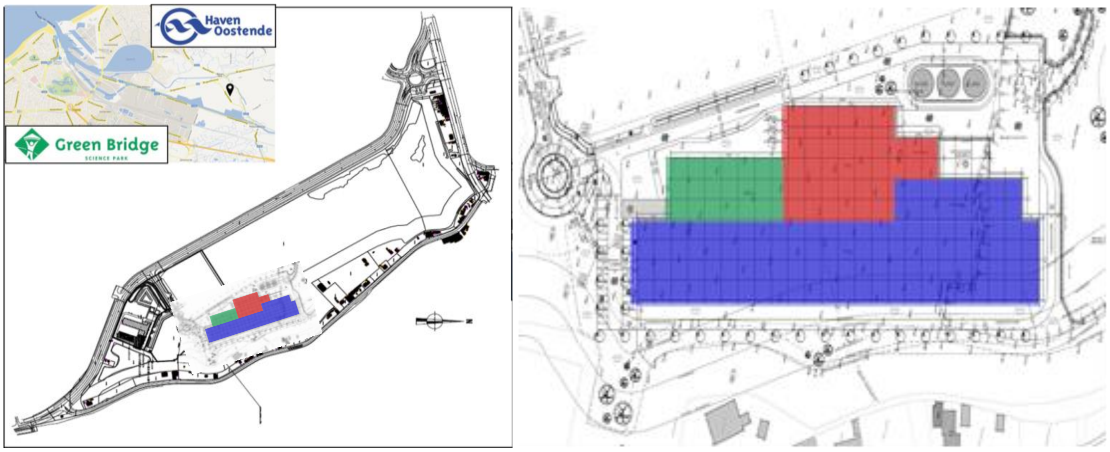

Figure 2. Top - Location of the upcoming physical modelling research cluster near the port of the Ostend. Bottom - red upper right part: COB main hall, blue lower part: towing tank, green upper left part: shared office space.

3.2. Basin Facilities

The COB laboratory (52 m × 42 m) will host the basin (30 m × 30 m) and several autonomous systems that allow to achieve its full capabilities (Figure 3). The main COB systems are the wavemaker, and the current and wind generators, and the water transfer system. All of them are connected to the Data Acquisition System (DAQ) which allows the smooth and perfectly controlled set-up, start-up and management of any testing scenarios and parameters. Moreover, other auxiliary systems are necessary for the efficient operation of the COB, namely: the bridge crane (Figure 3, Part 5), the carriage or access bridge (Figure 3, Part 6), the fork-lift and the wheel loader. These devices are described below.

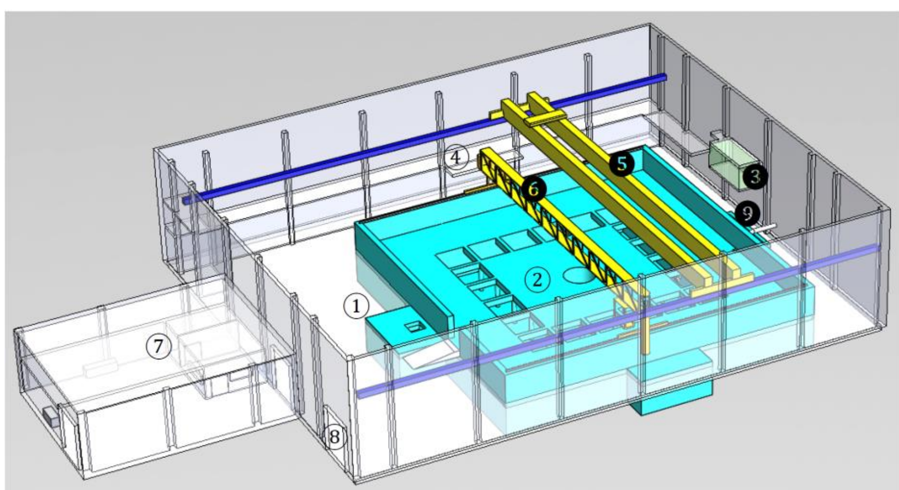

Figure 3. Overview of the layout of the COB facility: 1) main hall, 2) COB basin, 3) main operation control location and office, 4) secondary operation & observation control location, 5) bridge crane, 6) carriage (access bridge), 7) workshop, 8) external access, and 9) water transfer system.

An overhead bridge crane (Figure 3, Part 5) with a capacity of 7 tons will be available to displace heavy items in and out of the area of the wave basin (Figure 3, Part 2) i.e. scale physical models, structures, equipment, wind generator, etc. The bridge crane will cover the entire area of the COB laboratory (area within the external walls shown in Figure 3). The wave basin will be accessible with an electric fork-lift or a wheel loader in order to enable an easy model construction. Moreover, it will facilitate easy visits and access to the scale model and the employed instrumentation in order to make observations and any necessary adjustments during the testing. The operation of the basin will be steered from two control locations (Figure 3, Parts 3 and 4).

Furthermore, the COB will be equipped with an access bridge or carriage (Figure 3, Part 6). This is a mobile structure which allows the users to reach every location or instrument in the basin without having to enter the water. These "dry" conditions facilitate the work of the researchers. Also, the access bridge (or carriage) provides a close view of the experiments.

Furthermore, working with scale models and operating such a large infrastructure also requires a technical working space where equipment can be assembled, and model elements can be processed, manipulated and repaired. For this purpose, the infrastructure is provided with a workshop area (Figure 3, Part 7) next to the COB main hall. Furthermore, in the workshop area materials will be stored for the construction of models (stones in a variety of sizes for typical coastal engineering projects, guiding walls, support elements for instrumentation etc…). Cooperation in specific tasks with the towing tank staff will be possible.

3.3. Wave Maker

The wavemaker is the most important mechanical system of the COB. The wavemaker will be purchased through an international tender which required the careful and detailed specification of its technical characteristics. The first analysis towards the determination of these specifications involved the identification of typical physical modelling scenarios. Based on these results, important modelling parameters were defined.

Table 1. Selected examples of existing coastal wave basins in relation to the COB

Name	**Dimensions (length x width x water depth) (m)**	**Wave height (m)**
COB (Belgium)	30.0 x 30.0 x 1.40	0.55
Portaferry (QUB, Ireland)	18.0 x 16.0 x 0.65	0.55
DHI (shallow basin, Denmark)	25.0 x 35.0 x 0.80	est. 0.40
Univ. Hannover (Franzius-Institute) basin	40 x 24 x 1.0	0.40
Aalborg basin 2 (Denmark)	12.0 x 17.8 x 1.00	est. 0.50
Delta basin (Deltares, The Netherlands)	50.0 x 50.0 x 1.00	0.45
Pacific basin (Deltares, The Netherlands)	22.5 x 30.0 x 1.00	0.40
TU Braunschweig (LWI) basin	21 x 19 x 0.7	0.30
Tsunami wave basin (Oregon, USA)	48.8 x 26.5 x 1.37	0.75
Plymouth (Coastal basin, UK)	15.5 x 10.0 x 0.50	0.30
HR Wallingford (UK)	27.0 x 55.0 x 0.80	0.25

The wavemaker will ideally cover spatially two sides of the basin, forming an 'L'-shaped corner (indicated in Figure 4). This setup allows for a larger range of oblique (short-crested) wave angles. In addition, as the current generation can be reversed in direction, any relative angle between the current and the waves can be achieved.

The COB will be able to cover test conditions from coastal to near offshore. In Table I, a few examples of existing coastal wave basins are presented, in relation to the COB. The wave height in existing coastal wave basins is often limited by the operational water depth which is often related to the horizontal dimensions of the basin for most of the 3D coastal models. The COB will allow testing of coastal models in up to 1.4 m water depth with a maximum regular wave height of 0.55 m.

In a similar way, the COB will offer the additional capability to test offshore scale models. In Table 2, the most representative examples of existing basins are presented, in relation to the COB. In the case of the COB, the most relevant offshore applications are those related to marine renewable energy, i.e. wave and tidal energy applications, as well as projects related to wind energy such as testing of wind turbine monopiles. In addition, floating platforms and device mooring applications will be studied at the COB. Therefore, in order to cover the demand related to offshore projects, an overall water depth of 1.4 m has been adopted, while at the same time a central pit with a diameter of 3.0 m (indicated in Figure 4) and a water depth of 4.0 m will serve a.o. for mooring applications.

Table 2. Selected examples of existing offshore test basins in relation to the COB

Name	Dimensions (length x width x water depth) (m)	Wave height (m)
COB (Belgium)	30.0 x 30.0 x 1.40 (4.0 at central pit)	0.55
Ifremer (France)	18.0 x 4.0 x 2.10	0.30
Plymouth (UK)	35.0 x 15.5 x 3.00	0.40
Edinburgh (UK)	φ 30.0 x 2.0 (circular)	0.70
OTRC (USA)	45.7 x 30.5 x 5.80	0.90
Marin (Netherlands)	45.0 x 36.0 x 10.20	0.20
HR Wallingford (flume, UK)	75.0 x 8.0 x 2.00	1.00
MOERI (Korea)	56.0 x 30.0 x 4.50	0.80
Oceanide (France, USA)	40.0 x 16.0 x 5.00	0.80

For a wave basin like the COB, the capability for oblique wave generation is an extremely relevant aspect, which will be achieved by a wavemaker composed of relatively narrow paddles. The relation between paddle width and oblique wave quality has been investigated. The most demanding wave generation conditions occur for shorter waves when they are produced at a large angle relative to the normal direction of the wavemaker (Andersen and Frigaard 2014). The wave quality is typically specified as a spurious wave content for a specific wave period and angle, however, this criterion is difficult to be specified and measured. Therefore, a maximum paddle width has been specified as a design parameter. The maximum paddle width has been set to 0.67 m in the case of a snake-type wavemaker and 0.55 m in the case of a box-type wavemaker. These values will allow the high-quality generation of waves with 1.0 s wave period or higher in any oblique direction with respect to the wavemakers generators.

3.4. Current Generator

One of the unique characteristics of the COB is the capacity of generating combined waves, currents and wind loads. To our knowledge, there are very few facilities reported in the literature which offer combined wave and current generation. Consequently, experiments regarding combined waves and currents are also scarce (Lorke et al. 2011, Toffoli et al. 2013).

Table 3. Current systems in existing wave basin

Name	Dimensions (length x width x water depth) (m)	Flow rate (m^3/s)	Current veloc. (m/s)
COB (Ostend, Belgium)	30 x 30 x 1.4 (4.0 m depth at central pit)	11.2	0.40
Coastal basins			
DHI (shallow basin, Denmark)	35 x 25 x 0.8	1.2	
LNHE Chatou (France)	50 x 30 x 0.8	1.5	
NRC Canada	47 x 30 x 0.8	1.6	
HR Wallingford (UK)	27 x 55 x 0.8	1.2	
Pacific basin (Deltares, The Netherlands)	22.5 x 30 x 1	1.8	
Franzius-Institute (Germany)	25 x 40 x 1.0	5.0	0.35
QU Belfast (UK)	16 x 18 x 1.2		0.25
Cedex (Madrid, Spain)	34 x 26 x 1.6	0.2	
Offshore basins			
DHI (offshore basin, Denmark)	20 x 30 x 3.0	0.2	
Marin Offshore Basin (The Netherlands)	45 x 36 x 10.2		0.50
Marintek Trondheim (Norway)	80 x 50 x 10.0		0.25
CCOB Cantabria (Spain)	30 x 44 x 4.0	18.0	
Plymouth (Ocean basin, UK)	35 x 15.5 x 3		0.10
Flowave TT (UK)	φ 30 x 2.0 (circular)		0.80

It is important to note that an off-the-shelf solution for the current generation system does not exist, namely, the design of the current generation system requires a tailor-made solution considering the basin layout and target flow rates. The target current velocity is based on the dominating flow conditions in the Belgian coastal waters, characterised by tidal currents with a typical depth-averaged flow velocity of about 1.0 m/s. Considering a maximum scaling factor of about 1:8, the flow velocity in the model is scaled to 0.4 m/s. The current generation system of the COB aims at generating a steady current with an almost uniform depth-profile along a uniform water depth of up to 1.4 m, requiring a total flow of approximately 11 m3/s. A screening of existing laboratory facilities (Table 3) reveals that only few basins are able to generate currents with a velocity exceeding 0.25 m/s.

There is very scarce information on the quality of the flows that can be obtained by the different current system approaches. In the work of Robinson et al. (2015), experimental model measurements and numerical simulations are presented for the Edinburgh FloWave TT ocean energy research facility, stating that a turbulence level of approximately 10% was achieved. Some velocity profiles were also published for the flow systems of the Marin Offshore Basin in The Netherlands (Buchner et al. 1999, Buchner and de Wilde 2008), the Marintek in Norway (Stansberg 2008), the COAST basin in Plymouth University in the UK and the Ocean Engineering Tank of Japan (Toffoli 2013). The design of the COB current generation system targets to achieve a higher flow quality than that offered by almost all other existing infrastructures.

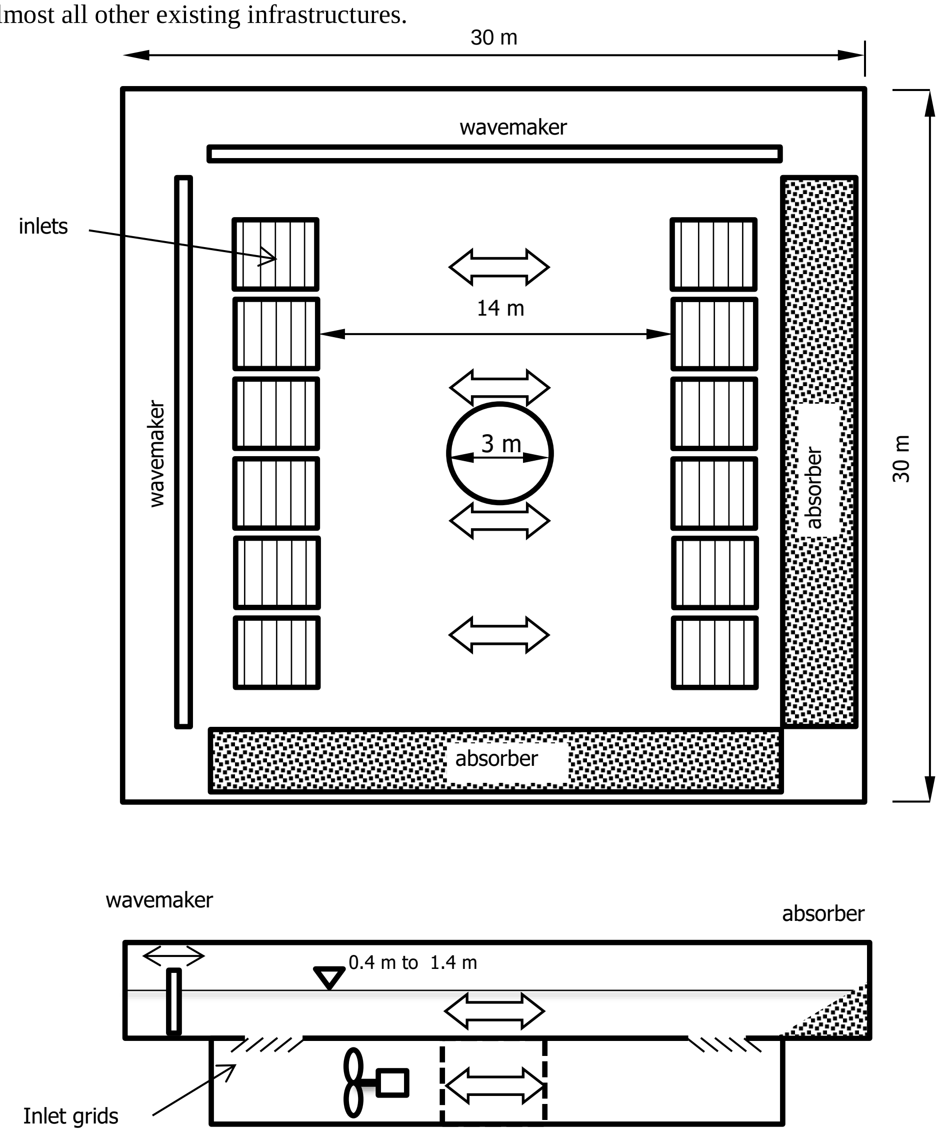

Figure 4. COB schematic including the wave generators at both sides (indicated as ‘wavemaker’) and the current generation system (top: plan view, bottom: cross section).

Current and wave facilities can be divided into three groups: jet induced flows, pump and pipe systems, and flow chambers. The first two systems are more compact, but they involve the presence of high velocities in different parts of their arrangement, resulting in relatively higher power requirements and even in current velocity limitations. For the COB, obtaining the highest flow quality while keeping the lowest operational cost possible is a priority. In this context, the use of a flow chamber below the level of the wave tank floor, namely a current tank, has been selected. A scheme of the current generation system is shown in Figure 4. The current is introduced in the basin through a number of guiding grids flush-mounted in the basin floor. Each grid can be replaced by a lid when the current system is not used.

In order to obtain a uniform and steady velocity profile in the COB wave basin, an approach has been adopted by pursuing the lowest possible velocities in the current tank and having successive velocity increases as the flow is guided to the wave tank. The last step is the 'turn' of the flow coming from the bottom of the basin so that it continues horizontally into the testing area; this has been achieved by designing an inlet guiding grid.

3.5. Instrumentation

An important objective of the COB facility is to provide state-of-the-art testing conditions. The COB laboratory will have a large inventory of traditional and state-of-the-art instrumentation for measuring e.g. the water free surface (i.e. capacitive, resistive, ultrasonic wave gauges), the wave orbital and current velocities (Acoustic Doppler Velocimeter, Acoustic Doppler Profiler, micro-propeller velocimeter), loading pressures, loading stresses (axial load cells), wind parameters and loads (ultrasonic anemometer, cup anemometer, barometer, air temperature sensor), and water depth. In addition, motion capture systems and a 3D laser scanner for topographic mapping are foreseen.

3.6. Data Acquisition System

The Data Acquisition System (DAQ) includes the analogue signal input from the instruments, the communication with the autonomous systems, the display and processing of signals and other information, and the data storage and back-up. The autonomous systems are those of the water transfer, the wavemaker, the current generator, and the wind generator. Figure 5 illustrates the general DAQ concept.

The DAQ will be able to cope with multiple experimental setups. The number of instruments connected to the analogue signal inputs may vary from one test to the next as well as the measurement locations. Therefore, we adopted a system with three acquisition "boxes" connected to an acquisition server by Ethernet. Each acquisition box offers an assortment of signal acquisition modules covering different possible sensors and acquisition speeds. The acquisition boxes can be easily repositioned in the COB laboratory to reduce analogue signal cabling to a minimum. There will be a total amount of 160 analogue input channels, 24 counter channels and 32 bridge or resistance channels.

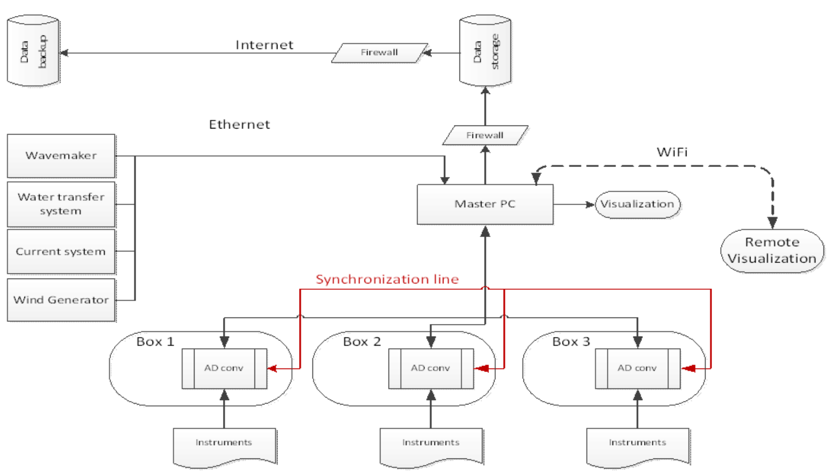

Figure 5. Schematic of the COB Data Acquisition System

Finally, the operation of the DAQ will be realised from two fixed locations in the COB facility: from the viewing room on the 1st floor (indicated as 'Main operation control location/office' in Figure 3), and from the cockpit located on the 1st floor corridor, at 90° from the viewing room (indicated as 'Secondary operation & observation control location' in). There will be also a remote, portable interface in order to be able to monitor the DAQ system from other locations.

4. Conclusions

There is a significant potential for wave and tidal energy in Europe which results in ample research activities focusing on different wave and tidal energy devices, systems and farms at various stages of development. Yet there is a clear need for a new infrastructure to be able to move from concept to open water (as recognized in various roadmaps at European level). At the same time, there is also a clear need for physical modelling infrastructure within the coastal engineering field, where updated knowledge on coastal protection schemes and methods, especially under 3D conditions and wave-current interaction, is still needed. The Coastal and Ocean Basin (COB) is serving the formulated needs. The COB will provide a versatile facility that will make a wide range of physical modelling studies possible, including the ability to generate waves in combination with currents and wind at various model scales, at any relative angle.

The different aspects of the design of the COB have been briefly presented demonstrating the criteria which have been used as guidance to each loading generation system and the decisions taken. The COB will not only provide state-of-the-art testing conditions but will also have unique technical characteristics amongst other well-known testing international facilities. These unique basin characteristics include in particular complex scenarios combining currents, waves and wind. The COB facility is currently under construction and the COB basin is expected to be operational from 2019 onwards.

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6. References

Andersen, T. L. and Frigaard, P. (2014). *Wave Generation in Physical Models: Technical documentation for AwaSys 6*. DCE Lecture Notes No. 34, Department Of Civil Engineering Aalborg University.

Buchner, B., Wichers, J.E.W., de Wilde, J.J. (1999). *Features of the State-of-the-art Deepwater Offshore Basin*. Proc. Annu. Offshore Technol. Conf.

Buchner, B. and de Wilde, J.J. (2008). *Current Modeling Experience in an Offshore Basin*. ASME 2008 27th International Conference on Offshore Mechanics and Arctic Engineering, American Society of Mechanical Engineers.

Folley, M., Babarit, A., Child, B., Forehand, D., O'Boyle, L., Silverthorne, K., Spinneken, J., Stratigaki, V., and Troch, P. (2013). *A review of numerical modelling of wave energy converter arrays*. ASME. International Conference on Offshore Mechanics and Arctic Engineering, Volume 7: Ocean Space Utilization; Ocean Renewable Energy ():535-545. http://dx.doi.org/10.1115/omae2012-83807.

Folley, M. (Ed.) (2016). *Numerical modelling of wave energy converters: state-of-the-art techniques for single devices and arrays*, 1st Edition, pp.306, ISBN: 9780128032107, Elsevier.

Lorke, S., Brüning, A., Van der Meer, J., Schüttrumpf, H., Bornschein, A., Gilli, S., Pohl, R., Spano, M., Říha, J., Werk, S., and Schlütter, F. (2011). *On the effect of current on wave run-up and wave overtopping*. Coastal Engineering Proceedings, 1, 32, 13.

Robinson, A., Ingram, D., Bryden, I. and Bruce, T. (2015). *The effect of inlet design on the flow within a combined waves and current flumes, test tank and basins*. Coastal Engineering, 95, 117-129.

Stansberg, C.T. (2008). *Current effects on a moored floating platform in a sea state*. ASME 2008 27th International Conference on Offshore Mechanics and Arctic Engineering, American Society of Mechanical Engineers.

Stratigaki, Vicky, Peter Troch, Tim Stallard, David Forehand, Jens Petr Kofoed, Matthew Folley, Michel Benoit, Aurélien Babarit, and Jens Kirkegaard (2014). *Wave Basin Experiments with Large Wave Energy Converter Arrays to Study Interactions Between the Converters and Effects on Other Users in the Sea and the Coastal Area*. Energies (2): 701–734.

Stratigaki, Vicky, Peter Troch, T Stallard, D Forehand, M Folley, JP Kofoed, M Benoit, A Babarit, Marc Vantorre, and J Kirkegaard (2015). *Sea-state Modification and Heaving Float Interaction Factors from Physical Modelling of Arrays of Wave Energy Converters.* Journal of Renewable and Sustainable Energy 7 (6).

Stratigaki, V. (2014). *Experimental study and numerical modelling of intra-array interactions and extra-array effects of wave energy converter arrays*. PhD manuscript, Ghent University. Faculty of Engineering and Architecture, Ghent, Belgium.

Toffoli, A., Waseda, T., Houtani, H., Kinoshita, T., Collins, K., Proment, D. and Onorato, M. (2013). *Excitation of rogue waves in a variable medium: An experimental study on the interaction of water waves and currents*. Physical Review E, 87(5), p.051-201.

Troch, P. and Stratigaki, V. (2016). Book Chapter 10: *Phase-resolving wave propagation array models*. In M. Foley (Ed.), Numerical modelling of wave energy converters : state-of-the-art techniques for single devices and arrays (pp. 191–216). http://dx.doi.org/10.1016/B978-0-12-803210-7.00010-4 , Elsevier.