COASTAL & OCEAN BASIN AND TOWING TANK FOR MANOEUVRES IN SHALLOW WATER AT FLANDERS MARITIME LABORATORY

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In May 2019 Flanders Maritime Laboratory (FML) has been officially opened. FML is a new research laboratory with different facilities built in Ostend (Belgium), and operated by Flanders Hydraulics Research, Ghent University and KU Leuven University. FML hosts two state of the art model scale facilities for the maritime industry, namely a Coastal & Ocean Basin (COB) and a Towing Tank for Manoeuvres in Shallow Water. In 2019-2021 both installations will be instrumented. In the present paper a description of the instrumentation and the reasons behind the parameter selection is given.

The COB is a midsize wave basin (30 x 30 m²) with a maximal water depth of 1.4 m (adjustable between 0.4 and 1.4 m), and a deeper (4.0 m), central pit. Its principal aim is to study the behaviour of waves, winds and currents coming from different and independent directions on coastal defence and blue energy applications.

The towing tank will mainly focus at ship behaviour in shallow water and will be equipped with a state of the art planar motion mechanism (PMM) carriage, capable of steering the ship in four degrees of freedom, while letting her sink and pitch freely. At the same time this carriage will be used as a tracking device to follow a ship model in full free running mode (no rigid connection between model and carriage).

1. Flanders Maritime Laboratory

Flanders Hydraulics Research (FHR), Ghent University and KU Leuven University have a long term experience in model scale research covering both coastal engineering and naval architecture topics. The idea to extend and scale up the present model test research facilities was raised 10 years ago, due to the ever increasing demand on measurement quality and the increasing ship size. None of the organizations had separately sufficient funds nor space to build these larger scale model facilities, therefore it was decided to join forces and build a new laboratory (by the Maritime Access department of the Flemish Government) in Ostend. In May 2019 - after 27 months of construction - this new laboratory was baptised Flanders Maritime Laboratory (FML) and hosts two state of the art model scale facilities for the maritime industry: a Coastal & Ocean Basin (COB), jointly operated by Ghent University, FHR and KU Leuven University and a Towing Tank for Manoeuvres in Shallow Water, operated by FHR with the scientific support of Ghent University.

FML is located at the Ostend Science Park at the border of the Port of Ostend, Belgium (Figure 1). This science park covers about eighteen hectares and provides the necessary space and services for the basins, as well as for the development of future industrial activities.

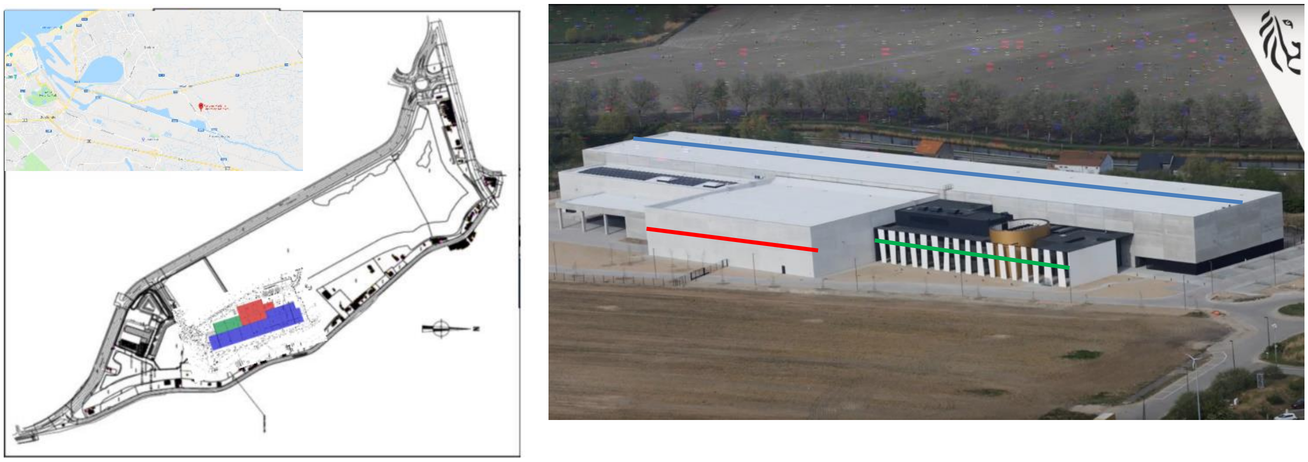

Fig. 1 – Location of FML near the port of the Ostend (© Google Maps). Red part: COB main hall, blue part: towing tank, green part: shared office space.

2. Coastal & Ocean Basin

2.1 Overview

The new Coastal and Ocean Basin (COB), Figure 2, is being instrumented within the context of the Gen4Wave project. The facility will cover a wide range of needs while keeping the operating costs as low as possible, which has led to the adoption of several unique solutions both in the management of the project and in the engineering approach.

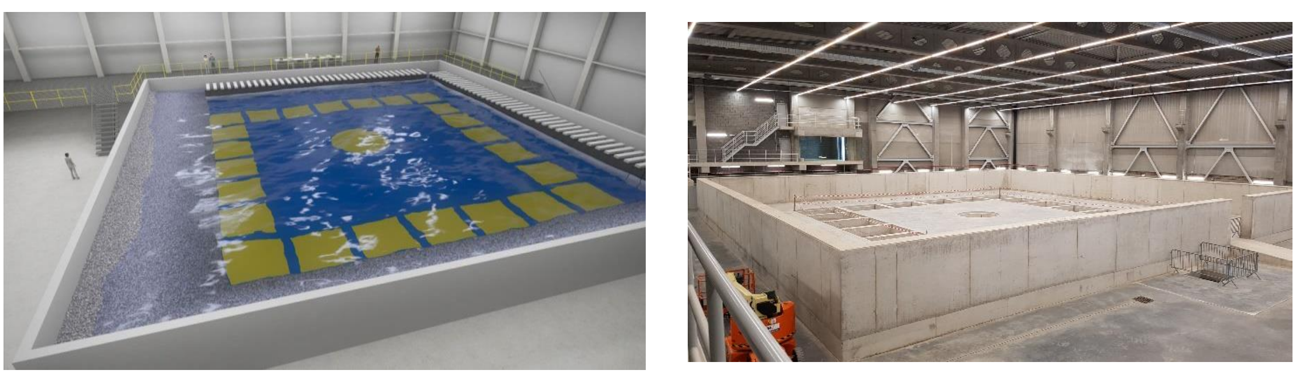

Fig. 2 – Artist impression of the equipped COB and current construction state

Flanders has a long tradition in coastal engineering supported by the experimental infrastructures of UGent (wave flumes) and of 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, focussing 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.

Some examples of research topics in these domains include the 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 [1]; the impact of combined wave and current actions on structures; and the prediction of wave overtopping at harbour quay walls.

These research questions, among others, will be tackled at the COB 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.

2.2 Basin Facilities

The COB hall (52 m × 42 m) hosts 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 wave maker, and the current and wind generators, and the water transfer system. 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.

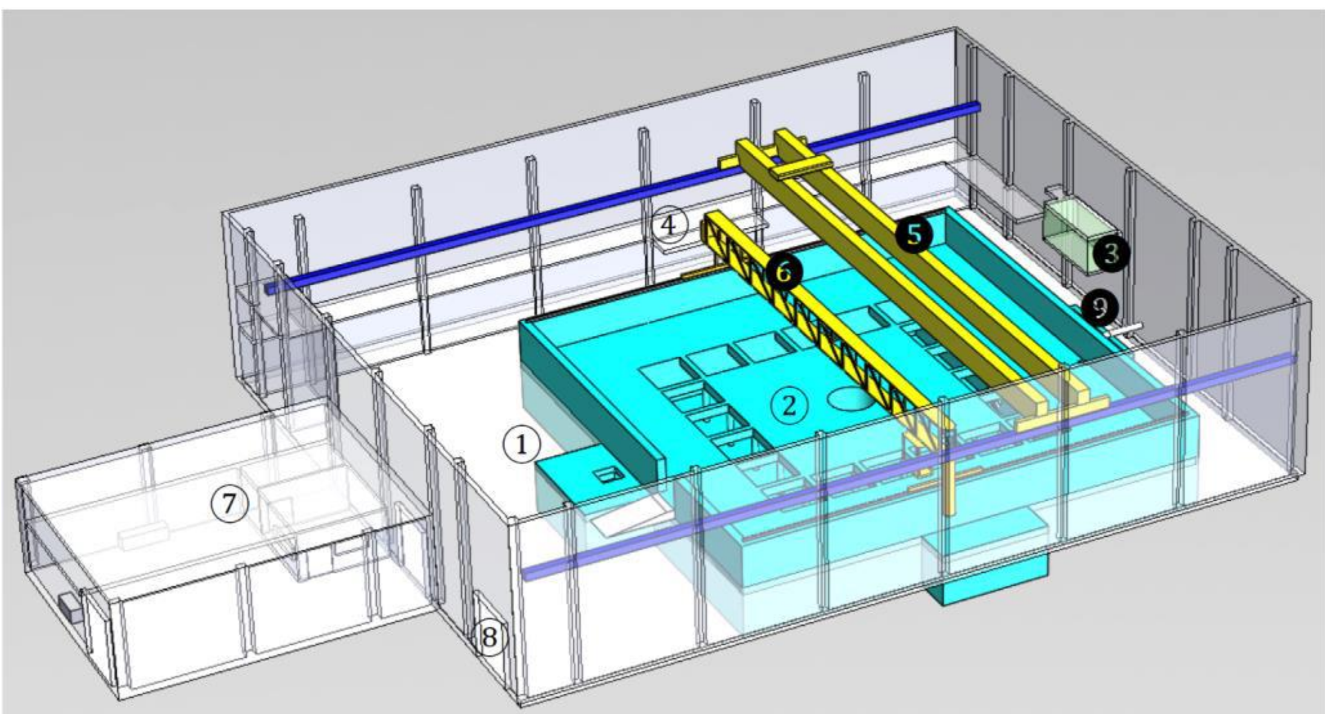

Fig. 3 – Overview of the layout of the COB facility: 1) main hall, 2) COB basin, 3) main operation control location and office, 4) secondary operation & observation control location, 5) bridge crane, 6) carriage (access bridge), 7) workshop, 8) external access, and 9) water transfer system.

The overhead bridge crane (Figure 3, Part 5) has a capacity of 7 tons 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 covers the entire area of the COB hall (area within the external walls shown in Figure 3). The wave basin is accessible with an electric fork-lift or a wheel loader in order to enable an easy model construction. Moreover, it facilitates 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 5, 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.

In the workshop area (Figure 3, Part 7), next to the COB hall, 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…).

2.3 Wave maker

The most important mechanical system of the COB is the wave maker. The first analysis towards the determination of the specifications involved the identification of typical physical modelling scenarios. Based on these results, important modelling parameters were defined. The wave maker 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 1, a few examples of existing 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 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 for mooring applications, among others.

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 [2]. 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 wavemaker generators.

Table 1 – Selected examples of existing coastal wave or offshore basins in relation to the COB

Name	**Dimensions (length x width x depth) [m]**	**Wave height [m]**	**Flow rate [m³/s]**	**Current velocity [m/s]**
COB (Belgium)	30.0 x 30.0 x 1.40 (4.0 at a central pit)	0.55	11.2	0.40
Coastal wave basins				
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	0.40 [1]	1.2	
Aalborg basin 1 (Denmark)	15.7 x 8.5 x 0.75	0.20		
Aalborg basin 2 (Denmark)	12.0 x 17.8 x 1.00	0.50 [1]		
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	1.8	
Atlantic basin (Deltares, The Netherlands)	75.0 x 8.7 x 1.00	0.45		
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	1.2	
Offshore test basins				
Ifremer (France)	18.0 x 4.0 x 2.10	0.30		
Plymouth (UK)	35.0 x 15.5 x 3.00	0.40		0.10
Edinburgh (UK)	φ 30.0 x 2.0 (circular)	0.70		0.80
OTRC (USA)	45.7 x 30.5 x 5.80	0.90		
Marin (The Netherlands)	45.0 x 36.0 x 10.20	0.20		0.50
HR Wallingford (flume, UK)	75.0 x 8.0 x 2.00	1.00		
KRISO (Korea)	56.0 x 30.0 x 4.50	0.80		
Oceanide (France, USA)	40.0 x 16.0 x 5.00	0.80		

2.4 Current generator

One of the unique characteristics of the COB is the capacity of generating combined waves, currents and wind loads. Very few facilities are able to test the combined wave and current action. Consequently, experiments regarding combined waves and currents are also scarce [3].

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

[1] estimated

approximately 11 m³/s. A screening of existing laboratory facilities (Table 1) reveals that only few basins are able to generate currents with a velocity exceeding 0.25 m/s.

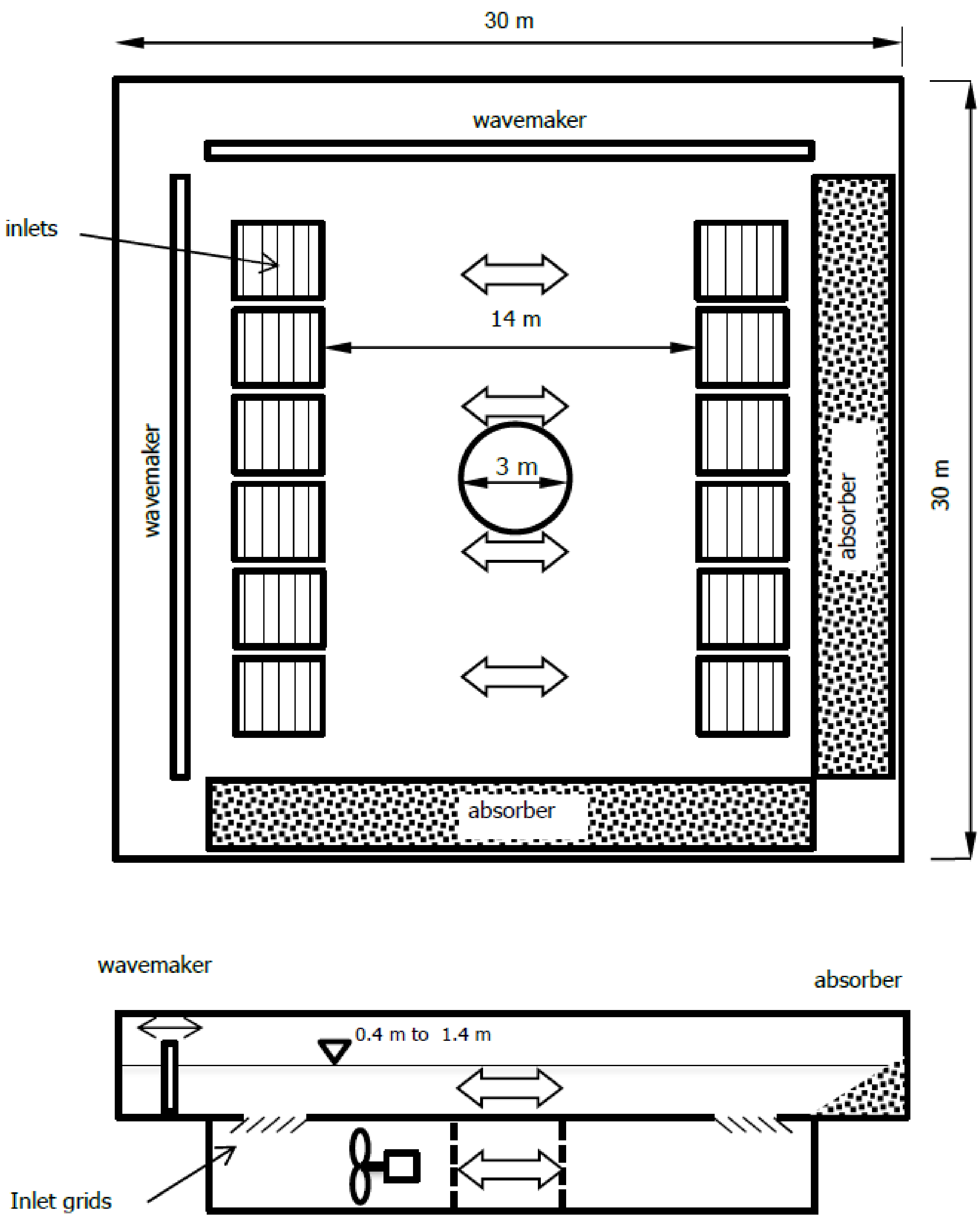

Fig. 4 – COB schematic including the wave generators at both sides (indicated as 'wavemaker') and the current generation system (top: plan view, bottom: cross section).

There is very scarce information on the quality of the flows that can be obtained by the different current system approaches. Experimental model measurements and numerical simulations are presented for the Edinburgh FloWave TT ocean energy research facility in [4], 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 [5], among others. The design of the COB current generation system targets to achieve a higher flow quality than that offered by almost all other existing infrastructures.

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.

2.5 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. Towing Tank for Manoeuvres in Shallow Water

3.1 Dimensions

The dimensions of the new towing tank are listed in Table 4 and show, compared to the dimensions of the present towing tank of FHR in Antwerp [6], a doubling in length and depth. The width of the new tank is almost three times the width of the first tank since tank wall effects cannot be sufficiently eliminated in the current tank, namely 7 m versus 20 m. This allows a maximum model length of about 8 m.

Table 4. Main dimensions of the towing tanks

		Ostend Shallow	Antwerp Confined	
Total lenth	**[m]**	174.0	87.5	(÷2)
Useful length	**[m]**	140.0	68.0	(÷2)
Width	**[m]**	20.0	7.0	(÷3)
Maximum water depth	**[m]**	1.0	0.5	(÷2)
Length of the ship models	**[m]**	3.5 – 8.0	3.5 – 4.0	(÷2)

The second towing tank has its dedicated hall of 192 m long, 30.6 m wide and 9.0 m high. The hall is equipped with an overhead crane and the measuring basin is located on the upper floor of the laboratory. On the ground floor, underneath the measuring basin, the water storage is located. This type of construction has two main benefits. Firstly, the water storage is evenly spaced under the measurement basin. This means that filling and emptying to achieve different water levels, will not create a differential loading of the foundation of the installation and thus minimize the risk of differential settlement of the foundations. Secondly, the double bottom construction creates an extremely stiff support system for the carriage which was necessary to attain the high vertical accuracy needed to perform high quality sinkage and trim measurements and to avoid varying position deviations due to deformations of the structure supporting the carriage, which would lead to undesired oscillatory velocity and acceleration components. Filling and emptying systems are installed at both sides of the basin to enable water level changes while minimizing fall of the water surface. The temperature and humidity are controllable within narrow ranges.

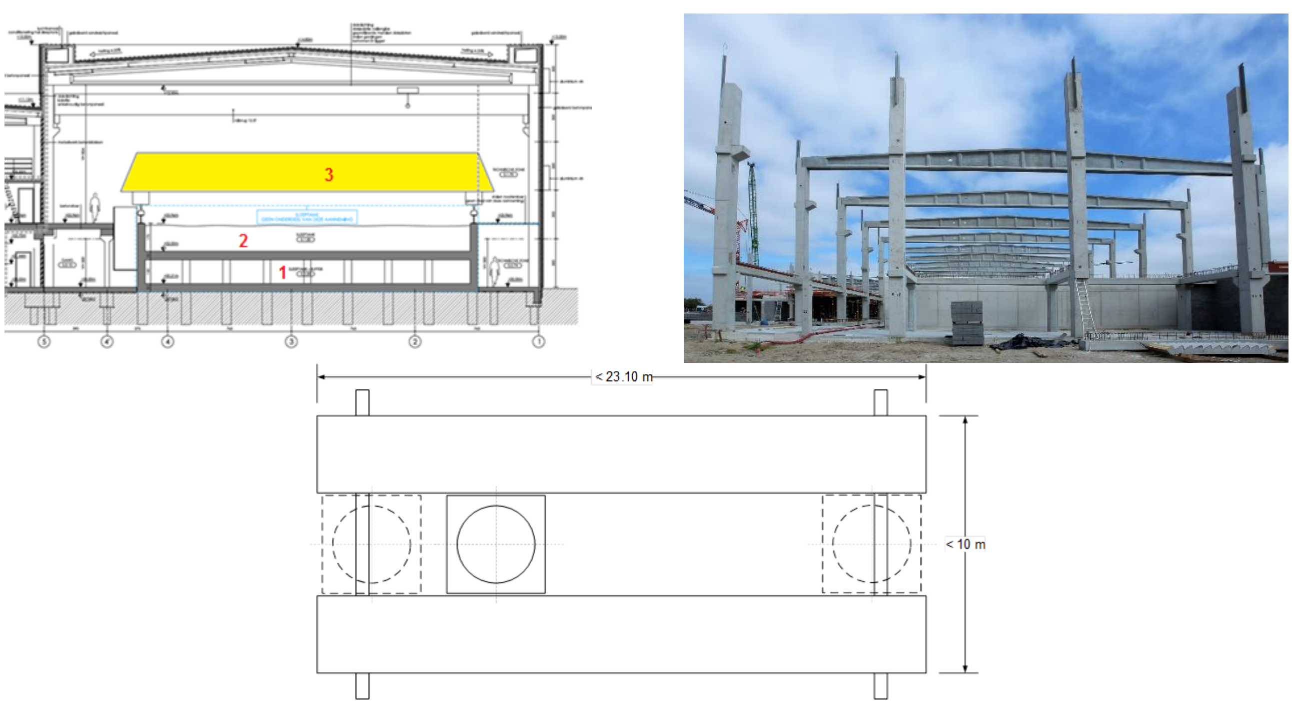

Fig 6 – (top left) Cross section of the towing tank hall showing the water storage (1), test basin (2) and schematic of the carriage (3).
(top right) View during construction.
(bottom) Carriage top view.

Figure 6 shows a cross section of the towing tank hall on which the water storage, the test basin and the towing tank carriage can clearly be identified. To enable the use of optical measurement setups, three viewing areas are provided. Halfway the test basin an observation window is made in the bottom of the basin (Figure 7). This window spans the width of the basin and enables optical measurement setups over the complete width of the tank. At two discrete locations, side viewing windows will enable the use of optical measurement methods from the bottom of the basin to the maximum attainable water level.

Fig 7 – Left: bottom observation window. Right: harbour section (view at wide dock).

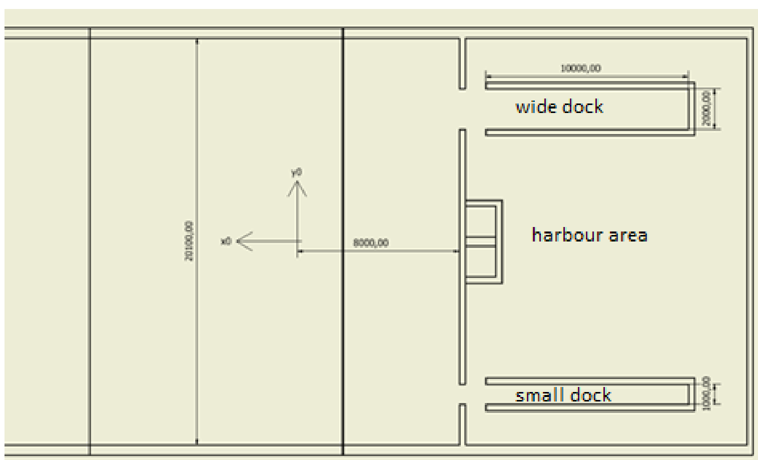

Fig. 8 – Detail of the tank at the origin of the tank coordinate system. The connections between tank and harbour (with two docks) still needs to be designed hence the opening in between.

At one end of the tank a harbour section is built to prepare the ship models. Mind that two docks are implemented: one for smaller or shorter ship models (small dock, 1 m wide) and one for wider or longer ship models up till 8.0 m long (wide dock 2, 2 m wide), see Figure 7 and Figure 8. The ship models are instrumented in the docks, which requires an ergonomic working height. Given the maximal water level in the tank, the height of the tank wall and the height of the second floor, the bottom level of the harbours is the same as of the tank bottom. In other words the harbour section will be at an intermediate level. The side walls of the harbours (1.20 m height) are lower compared to the tank walls. If the harbour would flood, the water will remain within the tank walls surrounding the harbour. Both harbours can be closed with a watertight door. The guiding rails of the carriage continue to the end of the harbours so that the longitudinal carriage can move the ship models into the harbours.

The towing tank has an eccentric position with respect to the hall. Next to the negative y_0- coordinate, towards the outer wall of FML, the available width will be only 1.80 m. This side will serve as a technical zone for example the, to be designed, power supply to the carriage. Power outlets with 240 V and 380 V are available. On the other side of the tank (positive y_0- coordinate), sufficient space should be available (4.10 m) to allow the passage of a fork lift truck next to the tank.

3.2 Shallow water challenges

Both FHR and Ghent University specialise in model tests in shallow and very shallow water. Therefore, the accuracy of the bottom is extremely important. An 8 m long ship model with a draft of 250 mm sailing with an initial UKC of 10% (common values for the projected experiments) has a gap of 25 mm between keel and bottom at rest. Taking into account the squat (both trim and vertical sinkage) this gap decreases even more. Therefore, an uncertainty of e.g. 5mm of the bottom (relative to the free surface) would be unacceptable for these kind of tests.

In terms of restricted water, the effects of banks, quay walls or other harbour structures is intensively investigated. The accuracy of the side walls is also of the upmost importance. The first towing tank in Antwerp was built with much care of accuracy. In the end, the only way to achieve the desired accuracy of the bottom, was to mill the bottom using the towing tank carriage with a vertical tolerance of 1 mm. It was therefore decided to design the new towing tank basin using this method from the beginning. A finishing layer will be applied in excess to the tank bottom and side walls. This finishing layer will then be milled using the towing tank carriage as support and position frame for the milling machine. Using this system reduces somewhat the built accuracies for the concrete construction. They remain nevertheless rather stringent. An added bonus of using a finishing layer is that by using a clever way to elastically bridge the expansion seams of the concrete construction, a continuous smooth bottom can be achieved. The deviation of the side walls with respect to the x_0 axis of the towing tank is not larger than ±10 mm with a gradient of maximal 1 mm/m.

Not only the bottom needs to be accurate to enable shallow water testing. The vertical accuracy of the rails of the main carriage determines the usability of the installation. The train rails, with polished upper surface, will therefore rest on a supporting system as shown in Figure 9. The rails are supported by blocks every 50 centimetres. The blocks can be moved up or down by rotating nuts on sturdy threaded rods. In this way, the rails can be positioned vertically with sub-millimetre accuracy. The desired vertical position is determined by measuring the vertical distance from the carriage to a reference water level.

By means of lateral guiding wheels on one of the rails excessive lateral deviations of the carriage can be avoided. The lateral surface of this rail will also need a specific coating. It is important to limit the (vertical) movements of the rails. The position of the rails, both in vertical and in horizontal direction, has to be adjustable. The accuracies for the rails are as follows:

- Vertical deviation < 1 mm (full length), < 0.2 mm level difference between both sides of the tank;
- Lateral deviation in the horizontal plane: < 0.4 mm (full length for the lateral guiding rail), < 0.8 mm (full length for the other rail).

- Maximal steepness in the vertical plane < 0.1 mm per 1 m;
- Maximal steepness in the horizontal plane: < 0.2 mm per 1 m (lateral guiding rail), < 0.4 mm per 1 m (other rail);
- Maximal deviation of the width of the running surface: < 0.1 mm.

The width of the rails has still to be determined during design.

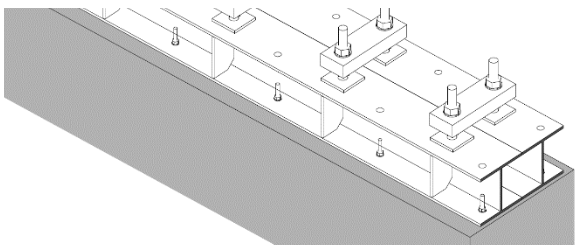


Fig. 9 – Left: design of the rail support structure. Actual rails not shown. Right: current construction, including view of the side windows.

Due to the frequent water level variations a performant emptying and filling system has to be available, transferring the water between the reservoir below the tank and the experimental section. The pump system is designed to be used by the towing tank only. The discharge design rate of 1000 m³ per hour (allowing level variations in ½ working day) is obtained by a set of pumps, e.g. four, to have a redundant system and to enable smaller discharge rates as well, e.g. for smaller water level changes.

The filling and emptying actions move the water between the tank and the underlying water reservoir with a capacity of 3,600 m³, which is 120% of the maximal water volume in the tank. The pumps are located within the water reservoir and the connection with the tank is located between x_0 = -1 m and x_0 = -4 m, as close as possible to the side walls. The wave damping mechanism should be designed to cope with filling and emptying actions. A useful extension is the automation of the water levelling, which includes the adaptation of the height of the connection mechanism (see next section) and that the safety against bottom touch is guaranteed.

Each harbour has its own dedicated pump to enable independent filling actions. Both harbours can be closed with a watertight door so that each harbour can be levelled independently from the other harbour or from the tank and calibration can be carried out during the execution of model tests in the towing tank.

3.3 Towing carriage

The functionalities of the shallow water towing tank are based on the experience gained over 25 years of shallow water towing tank testing at FHR. Like the confined towing tank in Antwerp, the new carriage will be fully automated to enable 24/7 testing. Automated testing is important since a large number of parametric variations are necessary to achieve enough data to build an accurate mathematical model of the ship behaviour, especially when covering harbour manoeuvres in shallow or confined water. Fully automated testing requires machinery with a very high degree of reliability and a very high safety standard. Safe zones for witnessing tests on and off the carriage will be created to allow researchers and clients to approach the ship models during tests and provide ample video registration.

The kinematics of the carriage are shown in Table 5 in case of 6 DOF steering. These kinematics allow for shallow water manoeuvring testing with ship models of displacement cargo vessels, such as bulk carriers, tankers or container vessels. Observe that in the beginning a 4 DOF steering system will be deployed allowing the ship model to freely heave and pitch.

Table 5. Kinematics of towing tank carriage (maximum values) in case of 6 DOF steering

DOF	Velocity	Acceleration	Jerk
Surge	3 m/s	0.4 m/s²	0.4 m/s³
Sway	1.3 m/s	0.7 m/s²	0.4 m/s³
Heave	0.7 m/s	0.7 m/s²	0.4 m/s³
Roll	16 °/s	32 °/s²	64 °/s³
Pitch	16 °/s	16 °/s²	16 °/s³
Yaw	16 °/s	8 °/s²	4 °/s³

The carriage's weight is estimated at 100 tons and consists of a main carriage, a transverse carriage and a yaw table. The yaw table will allow for vertical positioning of the model towing posts. The transverse carriage will move above the tank walls to allow very close sailing of the ship model to the tank walls to investigate bank effects. The synchronised driving of the motion axis will enable any continuous movement in the horizontal plane.

The yaw mechanism is considered to be a hollow tube with inner gear teeth with estimated diameter R_{ym} of 3 m, in which different sub setups can be (dis-)connected:

1. Free roll, heave and pitch (3 DOF carriage, in which the ship model is captive in all directions in the horizontal plane);
2. Roll mechanism (4 DOF carriage: this is considered to be the basic setup, in which the ship model is free to heave and pitch or heave and pitch are fixed);
3. Hexapod (3+ 6 DOF carriage);
4. Free running (carriage is used as tracking system).

The straightness of the longitudinal carriage (as a whole, measured with respect to the connection point of the ship) should have a minimal accuracy of 0.04 mm per 1000 mm. The straightness of the lateral carriage (as a whole, measured with respect to the connection point of the ship) should have a minimal accuracy of:

- 0.01 mm per 1000 mm in the horizontal plane, i.e. 0.2 mm over the tank width;
- 0.01 mm per 1000 mm in the vertical plane.

The reset positions of the longitudinal and lateral carriages need a position accuracy of ± 2 mm. This can be achieved by a position switch, which resets the positions when triggered. The longitudinal position switch should be moveable.

The reset positions of the yaw and roll mechanisms need a position accuracy of ± 0.01°. This is achieved by resetting an encoder after positioning the yaw or roll mechanism at the assumed zero point.
The accuracies of the hexapod should be of the same magnitude. The vertical accuracy should be 0.15 mm and the pitch accuracy 0.01° (1 mm per 4 m). More details on the accuracy requirements in the different modes can be found in Table 6.

The ship model has to be connected precisely to the carriage in such a way that alignment errors can be detected and corrected. In general the connection between ship model and carriage should be as straightforward as possible.

Table 6. Kinematic accuracy during tests

DOF	**Resolution**	**Position accuracy**	**Velocity accuracy (if steered)** The maximum of	**Acceleration accuracy (if steered)**
Surge	0.1 mm	1.5 mm	0.5 mm/s or 0.50%	0.5 N error:[2] 0.025 mm/s²
Sway	0.1 mm	1.3 mm harmonic sway motion: 0.70% motion amplitude and < 10 mm.	0.5 mm/s or 0.50%	0.5 N error: 0.025 mm/s²
Heave[3]	0.05 mm	0.15 mm	0.5 mm/s or 0.50%	2.5 N error: 0.050 mm/s²
Roll	0.01°	0.03° harmonic roll motion: 0.70% of the motion amplitude	0.08 °/s or 3.00%	0.1 Nm error: 0.08°/s²
Pitch	0.01°	0.03° harmonic pitch motion: 0.70% of the motion amplitude	0.08 °/s or 3.00%	0.5 Nm error: 0.03°/s²
Yaw	0.01°	0.03° harmonic yaw motion: 0.70% of the motion amplitude	0.08 °/s or 3.00%	0.5 Nm error: 0.03°/s²

[2] Acceptable errors on a ship model with a displacement of 1 ton.
[3] Italic values are valid for the hexapod

These accuracy limits have to be met, taking into account
– the cumulative deviations due to temperature variations Ft;
– the cumulative deviations due to the uncertainty induced by the position gauges Fv;
– the cumulative deviations due to the geometric accuracy of each sub mechanism Fg.

The cumulative deviation is computed by the square root of the sum of squares of each possible deviation. The computed value is then multiplied with a safety factor of 4/3. The outcome of this computation should be smaller or equal to the values mentioned in Table 6.

For the degrees of freedom that can be free the static friction force of the connection between the ship and the carriage may not be larger than:

- 2 N for the heave motion;
- 1 Nm for the pitch motion;
- 1/8 Nm for the roll motion.

The loads mentioned in Table 7 were scaled from the design loads of the carriage in towing tank 1. Any exceedance of loads activates a safety mechanism (e.g. abort a test). The loads with ship model apply on the ship model. The application point of these loads is thus 2 to 3 m below the base of the longitudinal carriage.

Table 7. Design loads

DOF	**Maximal load on ship model (Range of dynamometers)**		**Maximal load on carriage**	
	Captive mode	**Free running mode**	**Captive mode**	**Free running mode**
Surge	1.0 kN	p.m.	6.4 kN	p.m.
Sway	1.0 kN		8.0 kN	
Heave[4]	*10.0 kN*		*≥10.0 kN*[5]	
Roll	1.0 kNm		≥ 1.0 kNm	
Pitch	*8.0 kNm*		*≥8.0 kNm*	
Yaw	8.0 kNm		16.0 kNm	

The towing tank carriage will be erected in 2020. A tender for the design and built of the carriage and all auxiliary systems will be made available the second half of 2019.

3.4 Wave generation

A wave generation mechanism is foreseen at the positive end of the tank x_0 = +142 m. A wave damping mechanism has to be installed both behind and in front of the wave maker, the latter only when the wave maker is not operated. At present a piston type wave maker with segmented flaps covering the entire water depth (1.25 m) is preferred.

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[4] Italic values are valid for a hexapod

[5] A safety factor has to be agreed for ≤. The maximal weight of a ship model is for instance 65 kN. This load will apply when the towing tank is emptied involuntary. In such case a safety mechanism must be implemented, in this example the ship model could be lowered.

The limiting working conditions:

- maximal amplitude: +/- 0.5 m;
- maximal velocity: +/- 1 m/s;
- maximal acceleration: +/- 4.4 m/s²;

which allow the generation of 10 m long waves with a height of 0.2 m at water depths of minimal 0.4 m. The different flaps should allow the generation of waves with an angle up till 45° referred to the longitudinal axis of the tank (≤45°).

4. Conclusions

The realisation of state-of-the-art research infrastructure in Flanders will make sure that the Government of Flanders and the partnering universities of Ghent and Leuven can position themselves as an innovative, reliable partner for hydraulic and nautical research with a focus on shallow and confined water manoeuvring, coastal defence and offshore energy conversion.

The unique synergy that originates from combining the academic foundations of the universities of Ghent and Leuven with the operational experience of FHR, will make the COB a versatile facility that will make a wide range of testing possible, including the ability to generate waves in combination with currents and wind at various model scales, at any relative angle.

The realisation of a second larger towing tank will introduce FHR into the ranks of larger institutes. The addition of a dedicated shallow water manoeuvring basin with fully automated capabilities to the international community of test basins will prove to be a worthwhile effort by supporting clients directly or through partnerships with other institutes. FHR continues to dedicate its resources and develop its expertise in shallow and very shallow ship manoeuvring.

5. References

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