Marine current energy converter tank testing practices

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Abstract

The marine current resource is potentially large and could generate a significant part of the European Union's electricity requirements. Before the installation of marine prototypes, specific trials are necessary to evaluate the behaviour of each system and the ability to exploit tidal or marine currents.

This paper presents a feed back of Ifremer tank testing practices but not only, for marine current turbine energy converter characterization. The main objective is to investigate the potentiality of the common experimental facilities to reproduce in-situ conditions, accepting that their use will continue to reduce the financial risk to the developper.

1. Introduction

Many marine current energy converters are in a stage of concept validation for which an evaluation of the ability to exploit tidal or marine currents is needed even more flow conditions for marine devices are distinctly different than for similar technologies such as the wind energy industry. This ability is dependent on turbine and/or other concept performances and specific trials are necessary to evaluate the behaviour of each system before marine prototypes can be installed. Some interrogations like impacts on the flow, perturbations of the free surface and interactions with the seabed need to be investigated like for wind energy industry for which these questions are posed but in a more open environment [1].

At present, numerical modelling doesn't provide reliable enough results to prevent the need for tank testing before full-scale testing in the open sea. Tank testing is more repeatable than at sea and can simulate extreme events to improve concepts and designs. Unfortunately, no common practices are adopted to assess the performance and operational characteristics of conceptual and small prototype wave and current energy devices, even it is one of the objectives of the EQUIMARE European project. In order to give an overview of some current practices used for tank testing of marine energy devices at model scale, we present a feedback on Ifremer practices for current tank tests.

Tank testing methods used during Metri II program (which offers a free of charge access to Ifremer facilities) or private contracts and performed both on horizontal and vertical axis marine current turbine are analysed to assess the Ifremer practices [2]. From ocean weather condition considerations, we present how the different inflow parameters can be modelled in experimental facilities.

2. Experimental facilities for in-situ characteristics representation

Contrary to wind energy turbines, marine devices operate in a constrained fluid in the vertical plane. Due to their expected sizes, marine current turbines could potentially occupy a significant fraction of the total height of the operating fluid. For a typical first-generation site with depth close to 30m and a horizontal axis turbine of 15m diameter, the devices will be exposed to surface wave and boundary layer effects. This conducted to a non-uniform vertical velocity profile which has implications for both rotor loading and wake profile recovery.

There is little knowledge of the flow field properties at highly energetic tidal energy sites. Often peak flow speeds are measured but the nature of current profile, waves and turbulence and the potential effects upon tidal energy devices are uncertain.

Even if it is difficult to determine the site characteristics, it is even more difficult to reproduce experimentally all of them. We can easily study uniform current or wave effects on turbine behaviour by the use of a towing tank, a flume tank or a wave basin but it is not convenient to adjust the turbulence level of the flow or the vertical velocity profile. For example, the turbulence level in a towing tank is equal to zero (with no possible evolution) while it is of the order of 5% in the Ifremer flume tank [3] (Annexe 1). This turbulence level seems to be low compared to the in-situ one [4], but it can be increase by the modification of the honeycombs positioned at the entry of the trial section tank to achieve at the maximum (without any flow stabilization device) a value close to 30% of turbulence intensity level. Any comparison between towing tank and flume tank results seems to be carried out to evaluate the turbulence effects on turbine behaviour and turbine performances. It should be achieved in a near future to correctly experimentally characterize turbine behaviour, particularly in the move from single to multiple or arrays of devices: they will have to operate in high turbulent flows due to their presence which increase downstream turbulence through vortex shedding and wake effects.

Concerning the characteristics of the boundary layer, it is impossible to create a particular vertical velocity profile in a towing tank and it is difficult to change the flume tank ones. Some attempts were carried out to reproduce real seabed effects in a flume tank [5] but without any real success due to a variety of problems to recreate flow field conditions at small scales. Figure 1 gives a comparison of the well developed vertical velocity profiles in two facilities (Chilworth and Ifremer) and the classical 1/7th power law.

From these two first parameters, turbulence level and boundary layer, towing tanks seem to be not the more appropriate to carry out such tests.

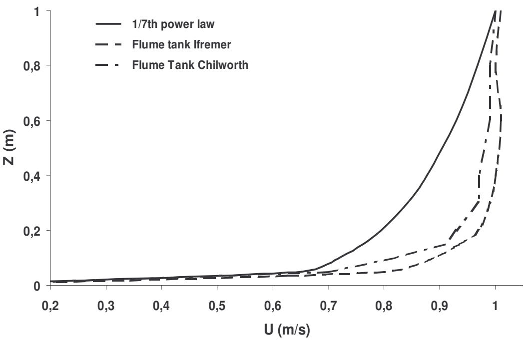

Figure 1: Classical 1/7th power law profile compared to the Ifremer and Chilworth flume tank one.

Some free surface effects like proximity of the boundary can be easily study with the use of flume tank like in [6]. However, waves prevail on the surface at tidal current sites. The combined effects of waves and currents on performances of submerged devices in 20-30m of water need to be better understood and predicted. Only few facilities offer the possibility to study combined effects of wave and current, even if a lot of facilities offer the possibility to study wave effects on the behaviour of marine devices under various conditions: regular and irregular waves of various amplitude and period. These experimental facilities are generally some wave basin for which the utilization of conveyor is required if we want to study both waves and current effects on marine current turbine. But unfortunately, the cinematic of such kind of trials is not in adequation with the real one.

The use of flume tank with wave generator is then required. But at our knowledge, such a facility doesn't exist with the characteristics requested for marine current turbine tests: for example, a velocity range between 0 to 2 m/s with peak-through height waves range between 0 to 30cm is needed at a scale of around 1/30, so a working section of 4 m x 2 m at the minimum.

From this fact, Ifremer decided to implement a wave generator in his flume tank (Annexe 1) in order to carry out combined trials in wave and current. The design of this new equipment will offer the possibility to produce regular and irregular waves with a period range between 0.8s and 3s and a maximum peak-trough height of 32cm, but not before the end of 2009.

3. Feed back from specific trials

In the following sections we present three experimental campaigns carried out on marine energy converter systems under METRI II program performed at Ifremer. All of them concern horizontal axis marine current turbine systems: a fully submerged machine in deep water and a "classical" pile-mounted tidal turbine concept. These testings are conducted to characterize the hydrodynamic load on the structure, the power output, the dynamic behaviour and effects on the flow. We will see from these trials who model scale testing can be carried out in a classical flume tank.

3.1. Fully submerged turbine (TGL's turbine)

Tidal Generation Limited are developing a fully submerged machine for deep water utilization. For that purpose and before the design of a 1MW tidal turbine prototype, trials on a 1/30th scale model (Figure 2) were carried out in the Ifremer flume tank. The purpose of this testing was:

- to investigate the dynamic behaviour of TGL's turbine
- to test the turbine power control strategy
- to measure the turbine efficiency
- to validate TGL's analytical rotor modelling tool
- to investigate fault case behaviour.

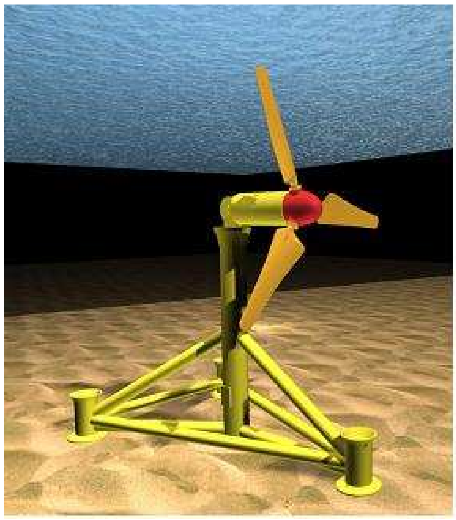

Figure 2: Fully submerged turbine developed by Tidal Generation Ltd

The model to be tested is designed to be mounted on a 6-component load cell in two configurations: *fixed upstream* and *free hinge downstream.* One of these two configurations is shown in Figure 3. A 3-bladed rotor is fixed on a motor-gearbox assembly capable to provide active rotor speed control (gearbox, DC motor, ballast load, motor speed control unit). The pitch of the 3 blades is adjustable. The diameter of the tested rotor is 0.6 m, which create a blockage ratio (percentage of cross section occupied by the rotor) of the model of approximately 4%. Those configurations are tested in the flume tank at speeds ranging from 0.6 to 1.5 m/s and the turbine performance obtained over a range of rotor speed from 10 to 190 rpm and blades pitch angle from –5 to 15 degrees.

Testing in the fixed upstream configuration allowed the performance characteristics of the rotor to be measured over the full range of current and rotational speeds. The mechanical torque of the turbine is given Figure 4 in function of the rotor speed for the 4 pitch angle tested (the flow tank speed can not be given here). The maximum performance is achieved for a 0° blade pitch angle over a short range of rotor speeds (between 100 and 120 rpm). For higher pitch angles (5, 10 and 15°), the maximum performance is achieved at lower rotor speeds (respectively for 70, 80 and 100 rpm). The measured performance of the turbine over its working range of current (0.6 to 1.5 m/s) and rotational speed is within 5% of TGL's analytical model predictions. The load predictions on the structure are also within 5% of model predictions.

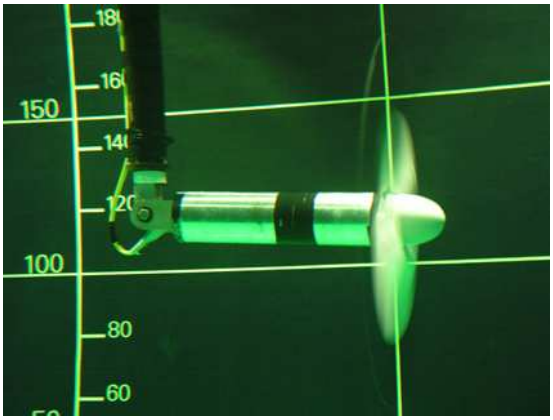

Figure 3: Free Hinge Configuration

Two power control strategies are tested to investigate sensitivity of turbine power output to natural turbulent fluctuations in the flow. Again close correlation is achieved with TGL's analytical model. Sufficient data is gathered to inform the design of the control system for the full scale 1MW machine that TGL is developing, allowing fluctuations in rotor torque and power to be minimised.

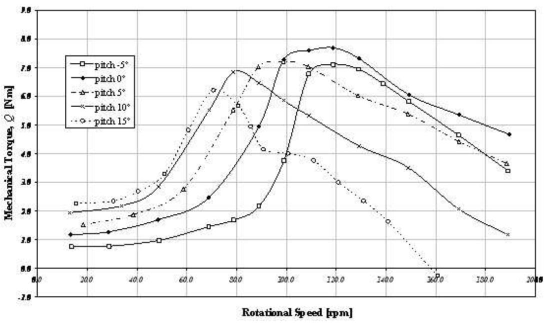

Figure 4: Measured rotor torque in the upstream configuration.

Free hinge downstream testing showed that the turbine is dynamically stable across the full range of current and rotational speeds in this mounting configuration. As intended, the rotor assumed a substantially horizontal orientation when generating (Figure 3).

Finally, the "gridloss" fault case scenario was simulated to investigate the loads acting on the turbine at full runaway. This data has helped TGL to develop an appropriate safety strategy for the full scale machine in the event of loss of reaction torque.

3.2. Porous mesk disk

In order to carry out comparison between two flume tank results, scale porous mesh disk rotor simulators (often referred to as actuator disks) were used. Actuator disks most accurately replicate the far-wake region where ambient turbulence is the principle mechanism of rotor wake recovery. To this end, the principle parameters that require accurate scaling are:

a) accurate replication of rotor disk thrust controlled through the level of porosity (ratio of open to closed area)

b) linear scaling of length ratios such as disk diameter to water depth and channel width

c) replication of ambient flow field conditions such as Froude number, vertical velocity profile and turbulence intensities. Full-scale and model Reynolds numbers cannot achieve parity at very small scales but should still lie within the turbulent classification.

100mm diameter disks were mounted on a thin steel support arm which was part of a pivot arrangement to mechanically amplify the small thrust forces on the disks (figure 1). A 10N button load cell was used to measure the total thrust force whilst a small deduction was made for the drag of the exposed section of the support arm.

Experimental work was conducted at two indoor facilities [7]. The first was the Chilworth hydraulics laboratory at the University of Southampton, UK, while the second one was the Ifremer flume tank, France. In order to visualise the flow field around the mesh disk rotor simulators a large number of point measurements were taken. A Nortek Vectrino Acoustic Doppler Velocimeter (ADV) was used for high frequency velocity sampling.

The experimental domains at both the Chilworth and Ifremer channels are detailed in table 1. The principle difference is that the Chilworth experimental domain consists of both the free surface and channel bed at 2 diameters from the disk centerline; the Ifremer set-up is similar except that the channel bed is very far below the disk such that there are no interaction effects. The closer proximity of the bed at the Chilworth facility influences the vertical velocity profile across and close to the disk.

Table 1. Physical properties of two experimental facilities used for experiments

	Chilworth flume	**IFREMER channel**
Total water depth	**4 Diameters**	**20 Diameters**
Channel width	**13 Diameters**	**40 Diameters**
Disk centre from surface	**2 Diameters**	**2 Diameters**
Depth-Averaged Froude No.	**0.118**	**0.113**

Ambient turbulence intensity is the principle mechanism for wake dissipation far downstream of the rotor disk. At the Chilworth facility the presence of the flume bed 2-diameters below the disk causes an increase in turbulence intensity immediately above the bed. At the IFREMER facility the turbulence intensity is more constant with depth close to the disk. The turbulence intensity in the vertical plane is much lower than at Chilworth.

Figure 5 shows the longitudinal centre plane velocity deficits for the experiments conducted at IFREMER and Chilworth. There is a degree of flow acceleration above and below the disk in the 4D deep flow that appears to persist far downstream close to the bed and water surface. The wake in the deeper flow appears to persist much further downstream; the deficit at 10-diameters is far stronger than for the shallower, constricted flow.

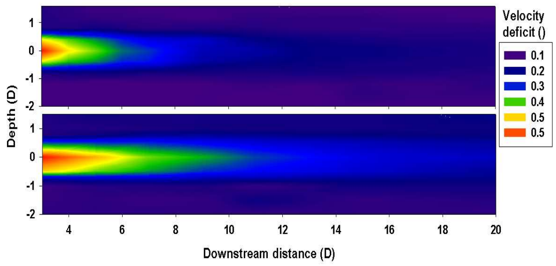

Figure 5: Centre plane velocity deficit profiles. Chilworth at the top and Ifremer at the bottom

Figure 6 shows vertical line plots of velocity deficit. The accelerated flow can be seen for the bounded conditions where the deficits close to the bed and water surface are very small or negative, the latter implying flow acceleration.

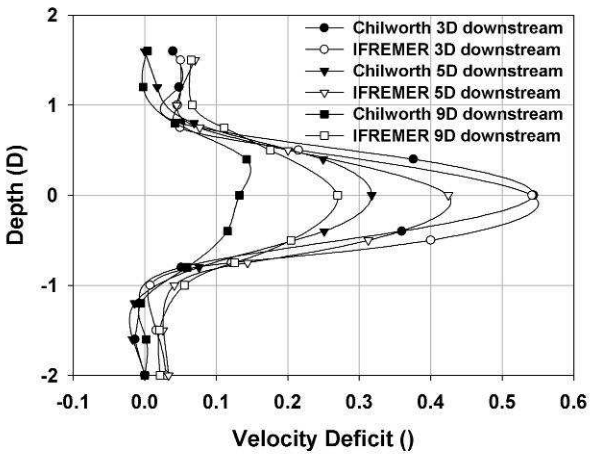

Figure 6. Measured vertical velocity deficit profiles at discrete distances downstream

Figure 7 shows the downstream centerline deficits. As suggested in figure 5 the wake recovers much faster in the more constrained flow. This may appear counter-intuitive as one might think that in a more open flow regime the wake is more free to expand. The principle reason could be due to the flow acceleration around the disk in a shallower flow pulls the wake downstream inducing increased shear forces that serve to break the wake up more rapidly. Flow in the deeper scenario does not accelerate above and below the disk to the same degree and the wake persists further downstream.

Data is included in figure 7 for 3 other flow mapping experiments conducted at the Chilworth facility [6]. These were conducted with a water depth of 3-disk Diameters and disks located at centre-depth. Results for varying flow speed or Froude number are presented to show that this parameter has little effect upon downstream centerline wake recovery. The reason for the slightly larger wake deficits at 3D compared to the 4D case in the same flume was due to the much larger difference in mass flow above and below the disks. Figure 6 demonstrates that the wake is symmetrical in the horizontal plane when the disk lies within a flow depth of 4D. For the 3D-depth the wake was suppressed downwards by the faster flow over the disk whilst increased velocity shear beneath the disk lead to a much lower mass flow passing beneath the disk. This reduced the amount of high-energy flow on the underside of the wake that would serve to re-energise and break up the wake.

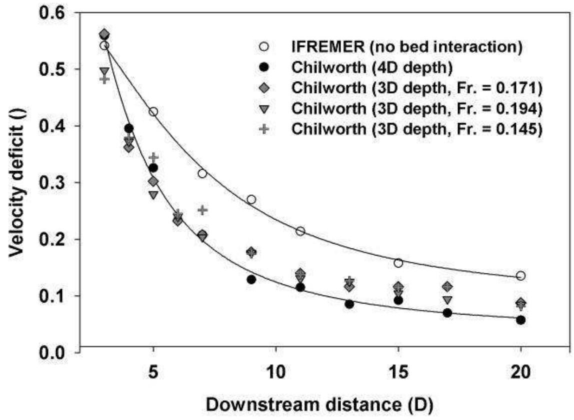

Figure 7. Centreline velocity deficit comparison

Thus the lower ambient turbulence in the vertical plane at the Ifremer facility can be ruled out as the reason for the lower rate of wake recovery. The lack of flow acceleration around the disk causes the wake to persist further downstream than for conditions where the disk is in closer proximity to both the water surface and bed.

3.3. Pile-mounted turbine (SERG's turbine)

Marine current energy conversion technology is presently at the prototype stage where single devices are deployed, or planned for installation, at isolated testing sites. In the medium term devices will be installed in arrays.

Understanding the effect devices have on the flow is critical in determining how one device may modify both the performance of and loading experienced by another device in the array. It is one of the aims of Southampton University work to identify and investigate the parameters which govern the wake structure and its recovery to the free-stream velocity profile. Scale model testing, presented here, is being conducted to aid the development of an efficient numerical model.

In order to increase our knowledge of those phenomenon, trials were conducted to evaluate performance and wake effects on horizontal axis marine current turbines. The measurements of flow effects around single and rows of turbine arrangements will be used to increase the knowledge of how such devices will perform when installed in arrays or farms of several machines. For that purpose, performance and flow (velocities and turbulence intensities in the wake of the system) measurements were carried out on a 1/15 scale model of a marine current turbine studied by the University of Southampton by laser velocimetry techniques.

The first part of the trials was dedicated to measure the efficiency and the wake behind a 0.8m diameter horizontal axis model, while the second part of the trials was dedicated to investigate the interaction effects of 2 turbines in close proximity. The maximum downstream distance between two single turbines can not be able to exceed eight meters in order to keep enough place for downstream flow measurements. During the testing, the global forces acting on the device for various configurations and speeds (between 0.8 and 1.6 m/s) could be measured with 6-component load cells. The flow characteristics will be measured with a 2-component laser Doppler velocimeter in the wake of the turbine. The turbine efficiency could be quantified by the measurement of the thrust and the amount of power generated by the rotor.

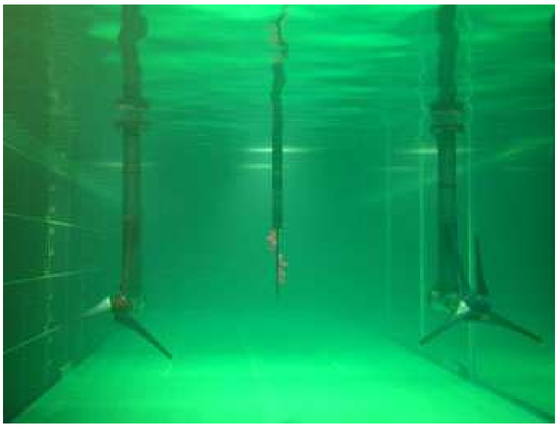

Figure 8. wake interaction effects characterization behind two turbines in close proximity

The results of these trials will be used first to quantify the lateral blockage effects on a row of single rotor devices closely spaced perpendicular to the incoming flow.

4. Conclusion

Three experimental campaigns carried out on marine energy converter systems under METRI II program performed in the Ifremer flume tank have been presented. These tesings were conducted to characterize the hydrodynamic load on the structure, the power output, the dynamic behaviour, the effects on the flow and wake effects on the performance of other device placed in close proximity and on the environment (free surface pertubation and seabed impact). For all of them, a specific assembly has been designed and a test programme carried out which provide good results and suitable data for validating theoretical and numerical methods.

Experiments to remove the effect of sea bed proximity have shown that wake recovery is not as favourable when the flow field is in effect infinitely deep beneath the rotor disk. In a symmetrical constrained flow there is acceleration around the rotor disk that reduces the length of the near wake where stronger velocity deficits exist. This faster moving flow persists into the far-wake region aiding breakdown of the wake and centreline velocity recovery. For flow depths shallower than 4-diameters the rotor disk is positioned closer to the more sheared section of the vertical velocity profile. This limits mass flow beneath the disk and reduces the rate of recovery on the underside of the wake.

All of these tests were carried out in an idealized field because recreating real field flow conditions at small scales holds a variety of problems. However, there is no doubting of the necessity to carry out trials at small-scale before full-scale prototype devices can be deployed at sea. Once detailed field data will be collected from tidal energy sites, efforts can be made to optimise the flow field reproduction at smaller scales so that tidal energy device performances can be improve by the development of the experimental facilities. For example, advances in facilities and testing techniques are required to investigate combined current-wave interaction and to validate numerical modelling techniques so that the latter can be used with confidence before deployment in open sea.

Acknowledgements

The European Union offers under the METRI II program a free of charge access to IFREMER Marine Environnement Tests and Research Infrastructure.

The author also would like to acknowledge and thank the following people for their implication in one or all projects: J-V. Facq, B. Gaurier for Ifremer, D. Dodd, J. King, J. Minto for Tidal Generation Ltd, L. Myers for Southampton University.

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Annexe 1

The Ifremer flume tank (Figure 9) is 18 m long by 4 m wide and 2 m deep with a side observation window of 8 m x 2 m. This large window placed on one side of the tunnel allows users to observe the behaviour of the models during trials and to carry out video sequences. The flow turbulence is less than 5 % and the flow velocity range is 0.1 to 2.2 m/s.

In this tank, we carry out trials on marine devices submitted to current effects (marine current turbines, tow fish, offshore structures…). In order to increase the potentiality of this facility and to answer to requests for particular studies, it was decided to implement a wave generator in the tank in 2009-2010. This new equipment will offer the possibility to carry out combined trials in waves and current. The main challenge will be to generate waves without changing the quality of the current in the tank.

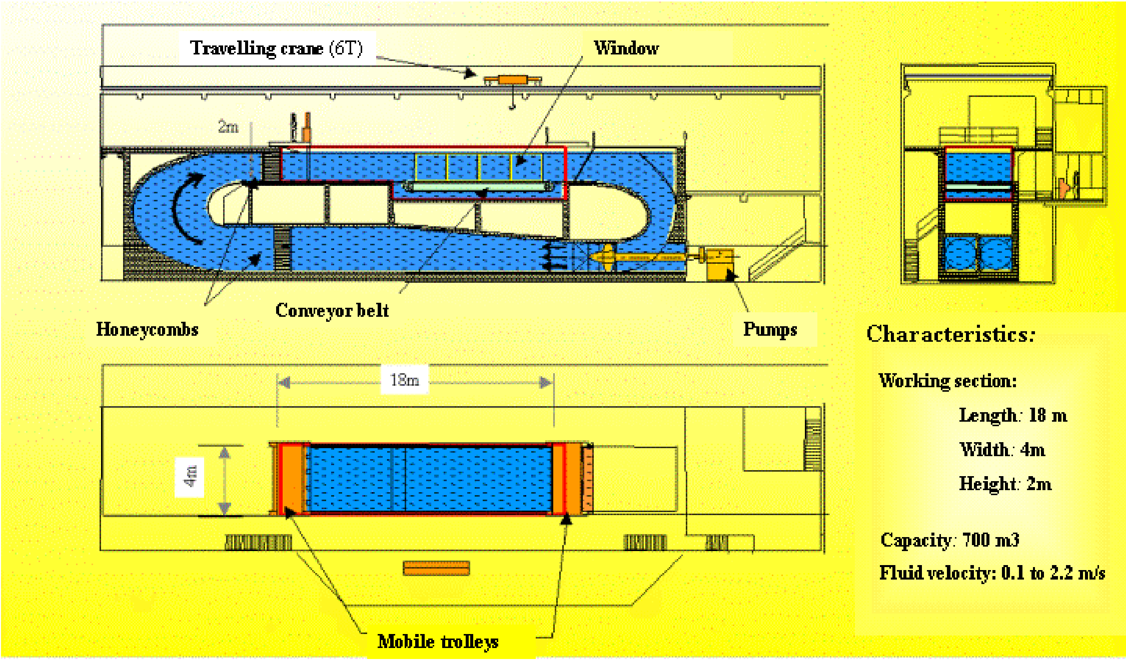

Figure 9: Ifremer free surface hydrodynamic water tunnel located in Boulogne-sur-Mer, France