Nontraditional Towing Tank Tests

M. Salas, C. Cifuentes, G. Tampier and C. Troncoso

Abstract Traditionally, towing tanks had been used primarily to assess the resistance of hulls in calm water, by means of towing geometrically similar scaled models at equal Froude number, usually without appendages such as rudder, propeller, and so on. When wave-making capability is available, towing tanks can also be used to determine seakeeping occurrences, such as green water effects and slamming, for a range of wave frequencies and amplitudes. This is not different for the University Austral of Chile Towing Tank, which has been involved in resistance and seakeeping tests of a variety of hulls, from fishing vessels to ferries, barges, and passenger ships, over the past 40 years. The development of marine industries other than shipbuilding, such as aquaculture, maritime connectivity of isolated geographical regions, and the harvesting of marine energy from tides and waves, have demanded a new set of tests with adequate models to properly replicate the physics of the full-scale case in the towing tank.

Keywords Towing tank · Nontraditional tests · Hydrodynamics

1 Towing Tank Description and Main Characteristics

The University Austral of Chile Towing Tank (Fig. 1) is a unique laboratory of its kind in Chile; it has played a key role in the development of the naval industry for more than 40 years. The tank main dimensions are 45 m in length, 3 m wide, and 2 m deep. It has an aluminum carriage running on lineal rails mounted with high precision, in order to guarantee accurate measurements. The towing carriage is equipped with a load cell, accelerometers, and ultrasonic sensors; if required surface and underwater cameras can also be installed. The carriage reaches a speed of up to 5 m/s and is driven by a servo motor of 0.75 kW.

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Fig. 1 University Austral towing tank

One end of the towing tank is provided with a regular wave generator, allowing it to generate waves up to 0.2 m in height. The tank walls and bottom are constructed entirely of steel and the structural frames are freely sustained by a system of flexible supports in order to withstand seismic movements.

The laboratory has a workshop for the manufacture of scale models to be tested. This workshop is equipped with a three-axis CNC milling machine (Fig. 2) capable of producing models up to 2.5 m in length, in materials such as wood, plastics, and aluminum.

The tests carried out in the towing tank allow the determination of advance resistance of hulls in calm water and in waves, visualization of flow lines, and dynamic response of ships and floating devices under regular waves, among others. The information obtained allows the selection, for instance, of the engine, propeller, and rudder of a ship, optimization of forms, and the behavior estimation of ships and buoyant artifacts in waves.

Fig. 2 CNC model milling machine

Recently the laboratory has been awarded a grant worth US$ 200,000 from the Chilean Government Office for the Promotion of Science. The grant will be used to provide new scientific equipment, namely a new wave generator that will be able to generate regular and irregular waves.

2 Wave Energy Converter Tests

Chilean energy demand has been growing over the past few decades and it is expected to remain so as the country develops. Traditional renewable energy sources as hydroelectric power are either fully exploited or face fierce opposition from environmental groups. In the present situation more than half the energy the country requires is produced by thermal plants burning imported and expensive oil, coal, or gas. The Chilean government is fully aware of this vulnerability and is making efforts to increase the contribution of nonconventional renewable energy sources (NCRE). It is intended that by 2025, 20% of the energy produced in the country will come from NCRE.

Recently important funding was awarded to create a Marine Energy Research and Innovation Centre (MERIC), a consortium of universities and research centers with the objective of promoting research in the field of nonconventional marine renewable energy (NCMRE). The University Austral de Chile through its Institute of Naval and Maritime Sciences (ICNM) is a partner of MERIC dedicated to investigate devices to capture wave energy, the so-called WEC (wave energy converter) mechanisms [1] and tidal energy harvesting.

Wave energy potential in Chile is among the largest in the world, with an energy potential that has been estimated between 164 and 240 GW [2]. Although the development of WECs has seen important advances in the last years, these are still considered to be in an early stage of development when compared to other NCRE technologies such as wind, solar, or hydro power.

Application of WEC technologies in Chile requires several aspects to be taken into account, considering local resource characteristics, potential environmental impacts, and/or available facilities for investigation, construction, installation, and maintenance. For these reasons, local capabilities for the development and adaptation of technologies are needed, with experimental scale model tests playing an important role. This section shows the evaluation of a scale model of a WEC; the response of different wave conditions was measured, as shown in Fig. 3. The experimental configuration for the converter consisted of two ultrasonic meters to record the WEC and incoming wave's movement. An adjustable damper was connected to a load cell and data acquisition software (LabView) to measure the force. Experimental results were compared with numerical results obtained by WAMIT, in the form of transfer function and output power [3]. The comparative data show good agreement for the variation of a set of parameters of wave

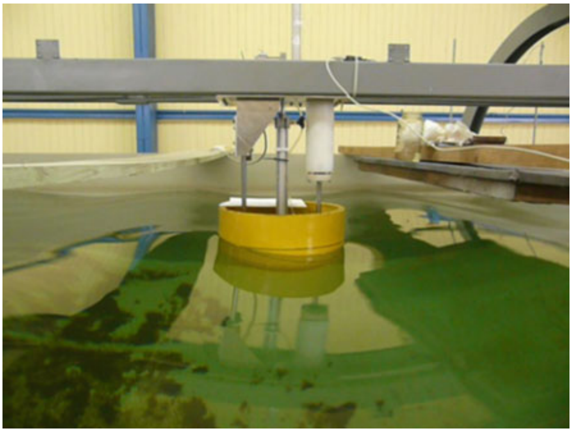


Fig. 3 WEC tests

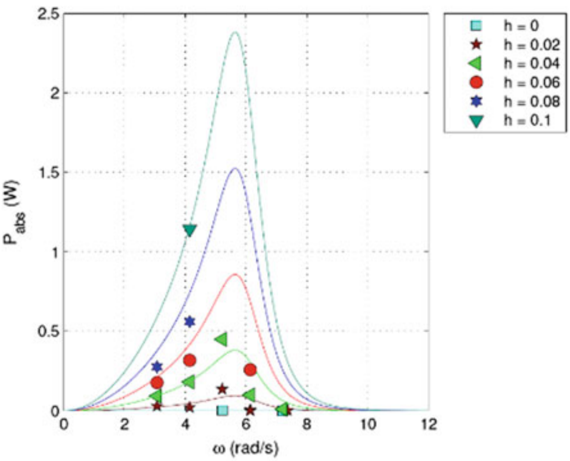


Fig. 4 Numerical and experimental results

frequency, wave height, and damping factors, as shown in Fig. 4. These developments are the first steps towards the specialization of this tank in experimental hydrodynamics of marine renewable energy technologies.

3 Floating Ports Modeling

Southern Chile is a region of extreme access difficulty; the existence of thousands of islands and canals makes the construction of roads extremely difficult. In many cases maritime transport is the only route of supply, therefore, appropriate ports and conditions must be provided to ensure the connectivity of those regions. The government of Chile has developed a connectivity program for remote regions that, among other solutions, has led to the construction of floating ports.

Conditions of southern Chile inland seas make the installation of floating ports advisable. According to Tsinker [4], these conditions are:

1. There are protected waters, where waves generated by the wind or the movement of ships do not exceed 1 to 1.5 m in height.
2. Where soil quality does not allow fixed structure foundations.
3. The change in sea levels is a high product of great tidal difference.
4. In seismic zones, because floating docks are less affected by earth movements during an earthquake.

A floating port is mainly a collection of pontoons with appropriate land access and a suitable mooring system to secure it in the operating location. Depending on the port's design requirements, it can be designed using various pontoon configurations, including one or more modules attached by a continuous cover or a pivoting mechanism. Although it is a simple hydrostatic problem, careful attention should be paid to the displacement of rolling loads on deck, so as to avoid displacements or rotations of the pontoons that may prevent proper operation; see Figs. 5 and 6.

In addition to the static analysis of the pontoons' loading, dynamic effects should also be considered, and environmental loads such as waves or the effect of wind should be taken into account. Dynamic analysis of vessel motion is well documented, however, for floating structures the problem has additional variables. Due to the complex interaction between floating structures, anchoring, and the fluid, it is advisable, in addition to analytical studies and numerical simulations, to carry out experimental tests with scale models. Tests should consider characteristic waves

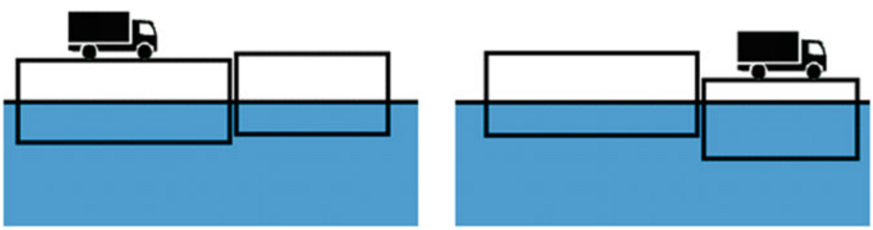


Fig. 5 Effect of moving load across pontoons with different buoyancy

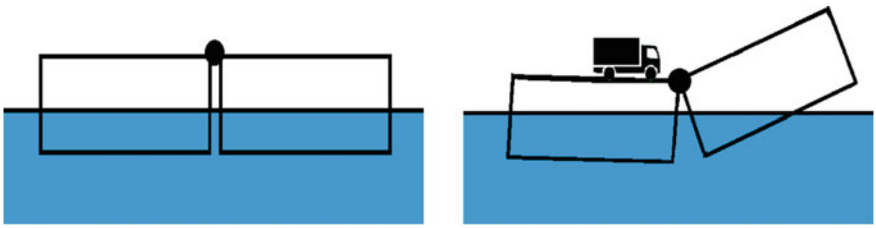


Fig. 6 Effect of moving load on deck formed by hinged pontoons

Table 1 Criteria for acceleration and roll (NORDSFORK, 1987)

Description	RMS vertical acceleration (g)	RMS lateral acceleration (g)	RMS roll motion (°)
Light manual work	<0.20	<0.10	<6.0
Heavy manual work	<0.15	<0.05	<4.0
Intellectual work	<0.10	<0.05	<3.0
Transit passengers	<0.05	<0.04	<2.5
Cruise liner	<0.02	<0.03	<2.0

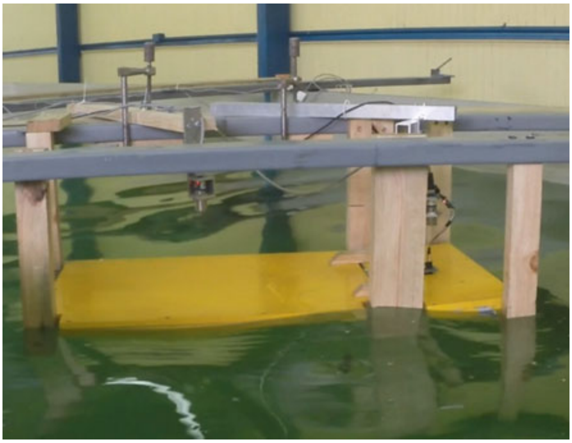


Fig. 7 Typical fetch wave. $H_{1/3}$ = 0.52 m, T = 2.99 s

and the bathymetry of the site where the floating port will be located. It is important to determine the significant wave height and period that will force the closure of the port due to unsafe operating conditions. Taking as a criterion the limit that ensures comfortable working on the floating port, limits defined in Table 1 can be taken as an example.

In addition to the adoption of criteria to close port operations, the floating structure must be designed to survive extreme conditions that will ensure its life, for example, 100 years survivability. Figure 7 shows tank wave tests for a floating port model for Southern Chile, under typical conditions imposed by the zone's fetch. Figure 8 shows tests with waves with a 100-year return period.

Fig. 8 100-year wave. $H_{1/3}$ = 1.38 m, T = 4.15 s

4 Aquaculture Net Modeling

The development of large-scale aquaculture in countries such as Norway and Chile has raised the need to develop studies, both numerical and experimental, to determine the forces and corresponding deformation of flexible structures such as nets used in floating cages [5]. Aquaculture centers, mainly breeding salmon, operate with square or circular cages (Fig. 9), installed in protected areas such as bays and fjords, to avoid the effect of waves and currents present in the open sea. The feeding of fish is carried out by automated systems installed on a pontoon, as shown in Fig. 10. The basic components of the cages are: a buoyant part that provides a flotation reserve to support the weight of the net and shapes the net that encloses the water volume with the fish. Hanging from the net are some weights that help to keep the net shape undeformed, or at least less deformed by environmental loads, mainly currents.

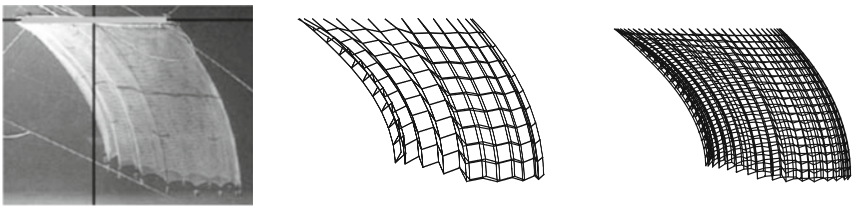
Fig. 9 Circular cage fish farming center. *Source* www.sermar.cl

Fig. 10 Control and feeding pontoon

The study of the hydrodynamic behavior of fish farming cages is complex due to the dependence between the drag force on the nets and the deformation of them. Similarly, for circular HDPE (high-density polyethylene) cages, the rings forming the buoyancy volume are deformed by the wave loads, directly influencing the tensions in the mooring lines.

In addition, the current velocity is reduced when passing through the nets, a phenomenon known as the shadow effect; this adds complexity to numerical and experimental modeling [6]. This effect works directly on the available volume inside the cages. Various studies, including the behavior of the fish inside the cages, biofouling on the nets, and flow into the breeding centers have been developed by various specialists to improve the production and increase the safety of these structures.

There are several numerical methods to estimate the hydrodynamic response of cages. Nets have been modeled using bar and panel elements in a finite element model; other finite element models use bars and buoys to adjust the submerged weight of the grid to create a reduced model of elements that simulates mechanical properties and net inertial forces in the physical model. An example of results obtained by the bars and buoys method can be seen in Fig. 11, which also includes the study of element density in direct comparison with the resulting deformation from experimental tests.



(a) Experimental model (b) Coarse numerical model (c) Fine numerical model

Fig. 11 Net shape deformation under current loads

As for the response of the cages to waves, it has been determined that the forces on the mooring lines are directly related to the wave height. When wave and current effects are simultaneous, depending on the combination of height and wave period and current velocity, the effect of the wave load can be of the same importance as the current load, which implies a careful modeling of both effects.

In exposed areas, fish farms should operate autonomously with minimal human intervention and the cage anchoring system will be shared with the platform containing equipment and fish meal. Results obtained for systems exposed to extreme conditions of waves and currents, both in numerical models and field tests, demonstrate the feasibility of the installation and operation of these structures and open the door for the future development of the fish farming industry in exposed zones. Open sea conditions are optimal for fish due to the constant exchange of nutrients in the water column. The almost unlimited availability of space would allow the production of a greater volume of fish, in addition to the opening to new species of greater commercial value.

5 Conclusions

Towing tanks are well-known experimental facilities, mainly dedicated to hull resistance and seakeeping tests, however, they can be adapted and implemented with instrumentation to perform a variety of experiments proved useful to many marine fields, such as aquaculture, marine energy harvesting, and floating ports among others.

Whenever possible, experimental measurements should be calibrated using benchmark tests, in order to avoid uncertainties in the predicted behavior of full-scale developments.

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