# Proposal of a Water Shallow Tank for Long and Capillary-Gravity Waves Based on a Numerical Simulation

Damiano Alizzio[a], Fabio Lo Savio[b], Giovanni Maria Grasso[c] and Marco Bonfanti[c]

[a]Dip. di Ingegneria, Università degli Studi di Messina, C.da Di Dio, 98166 Sant'Agata, Messina,Italy
[b]Dip. di Ing. Civile e Architettura, Università di Catania, Catania, CT, Italy
[c]Department of Electrical, Electronic and Computer Engineering, University of Catania, Catania, CT, Italy

### Abstract

In the scientific literature, wave tanks are widely used to reproduce and investigate the behaviour of surface waves and, particularly, the long waves. Most experiments are aimed to study the performance of wave energy converters. In order to analyse the basic properties of capillary-gravity waves (reflection, refraction, and diffraction) and related phenomena as interference, resonance and Doppler effect, ripple tanks are more suitable. In this paper, an instrumented shallow tank was designed to generate and observe both ripples and long waves. To validate the tank model, some numerical simulations were performed with an appropriate software, taking into account all the two-dimensional effects, including boundary and edge effects, relaxation and damping.

### Keywords

Wave Tank, Ripples, FEA, Damping

## 1. Introduction

Nowadays, the use of scaled and partially filled wave tanks and ripple tanks is common in the principal engineering applications concerning the study of the fluid motion under fixed conditions and, then, in the coastal and offshore engineering field. Their design derives from accurate numerical analysis based on the computational fluid dynamics (CFD). Indeed, the dynamic behaviour of a liquid within a container depends on many factors: the type of excitation and its amplitude and frequency, properties and depth of the liquid, tank geometry and size. The generation of waves is obtained at one end of the tank through suitable actuators, while the other end usually has a wave-absorbing surface.

The most common excitation types are periodic (sinusoidal, in particular) or impulsive, but random excitations are sometimes adopted. Another parameter to be considered is the resonance, which occurs when the tank motion frequency fits with one of the natural frequencies of the tank fluid. Under resonance, fluid motion within shallow tank can produce the so-called sloshing phenomenon consisting in high amplitude structural loads on the container [1].

As damping forces are generated by viscous boundary layers, their amplitudes have to be evaluated in the end of the tank opposite to the end intended for excitation. As known, the damping effect is affected by kinematics viscosity of the fluid and tank size. In the literature regarding numerical simulation, wave absorption techniques may be classified as active methods [2, 3, 4] and passive methods [5], whereas active methods are aimed to modify the computational results within a restricted zone or close to the boundary of the tank, while passive methods consist in implementing a certain slope in the tank to simulate physical beaches [6]. In particular, the relaxation method is a reliable wave absorption technique [2, 7, 8, 9, 10, 11, 12].

In the present work, a prismatic shallow tank was specially designed to reproduce and study both ripples and long waves within a certain frequency range. A finite element analysis with a specific software was carried out to simulate the behaviour of the waves under pre-fixed conditions.

The design included also a wave-absorption zone realized with an opportune slope to reproduce the damping effect of a natural beach. Tank dimensions were chosen in order to minimize both boundary effects due to side walls damping and the end wall reflection on the waves. Since waves were generated at one end of the tank and absorbed at the other end, the desired waves could be produced within the focus section placed

*ICYRIME 2020: International Conference for Young Researchers in Informatics, Mathematics, and Engineering, Online, July 09 2020*
damiano.alizzio@unime.it (D. Alizzio); flosavio@diim.unict.it (F.L. Savio); grasso.giovanni.maria@gmail.com (G.M. Grasso); bonfa.marco@tiscali.it (M. Bonfanti)

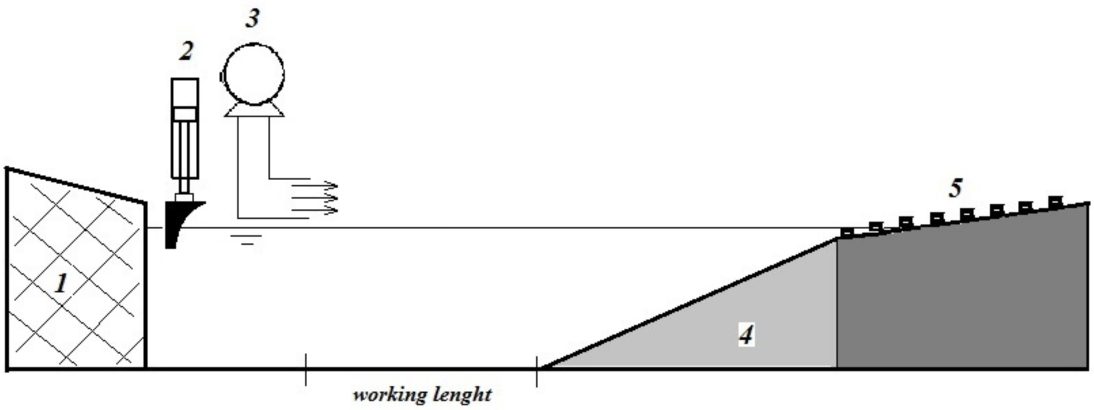


**Figure 1:** Schematic for the tank model: 1.Upstream wave absorption; 2.Wave-maker; 3.Fan; 4.Slope; 5.Sloped beach with obstacles.

just after the relaxation zone (equal to approximately 2 times the wavelength of the maximum wave expected) and in the middle of longitudinal axis of the tank; this representing the working zone. In the numerical simulation, the fluid adopted was distilled water that can be reasonably assumed to be homogenous, isotropic, viscous and Newtonian.

Under these assumptions fluid motions can be considered as three-dimensional and the fluid domain can be defined by the well-known governing equations of Navier–Stokes.

## 2. Tank Design

As shown in the schematic drawing of Fig. 1, a prismatic shallow tank in composites was designed to perform 3D-motion tests for long waves and ripples.

Regular long waves could be generated upstream using a suitable shaped wave-maker [13], having an alternating vertical motion and moved by an actuator operated by a home-made PC-controlled hydraulic system. The wave-maker profile is pseudo-parabolic so to generate sinusoidal-type long waves. The initial motion of the fluid particles should appear to be circular and this should indicate the low coefficient of friction thus obtained between wave-maker and fluid.

Ripples could be produced by a PC-controlled fan equipped with honeycomb filter in order to align the air flows right above the free surface of the water and positioned at the same end of the tank but immediately next at the wave-maker. Frequency working range was thought to be between 0 and 5 Hz. Such a design will allow studying separately the time-evolution of wind-wave fields rising from the initially calm water surface to the quasi-steady state at the given wind velocity, then the characteristic of ripples under steady wind forcing, and finally the decay of waves when wind forcing is abruptly shut down.

A double wave-absorption zone was designed: one at the downstream aimed to minimize unwanted reflection effects and the second at the upstream in order to avoid multiple bursts while wave generating.

Downstream wave absorption could consist of two parts: a) a $30^o$ slope beach starting at the end of the working area and ending at the beginning of the second beach; b) a $5^o$ sloped beach, where pyramidal polymeric dumping obstacles should be placed in 8 parallel arrays. Distance and transversal placement of obstacles were designed to achieve a damping effect not less than 35%. This result was obtained by placing the arrays of obstacles at a distance equal to one sixth of the minimal wavelength expected [14]. The wave reflected from obstacles was projected on opposite verse of generated wave and crushed in the backside of the previous array. This caused a significant turbulence and damping of reflected waves.

Upstream wave absorption could consist of a wave absorber (made of porous packing material) positioned at a higher level than the front edge of the tank with an emerging slope greater than 20%. The most appropriate tank design dimensions were found to be as follows: length of 6500 mm, width of 1000 mm, and height of 700 mm to guarantee a filling up to 500 mm.

A rectangular transparent inspection window was thought to be located in correspondence with the working zone. Its length must be enough to allow real-time visioning and video recording two consecutive wavelengths.

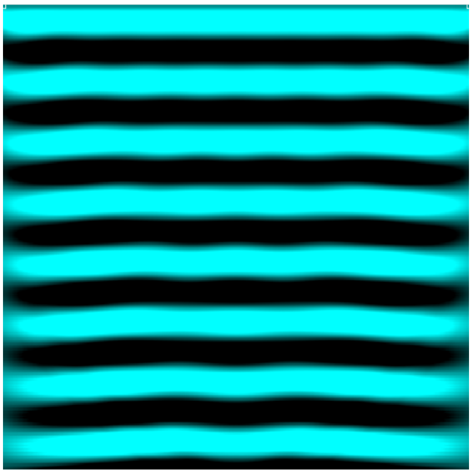

**Figure 2:** 2D Simulation, frequency 2 Hz, side border effect, no damping.

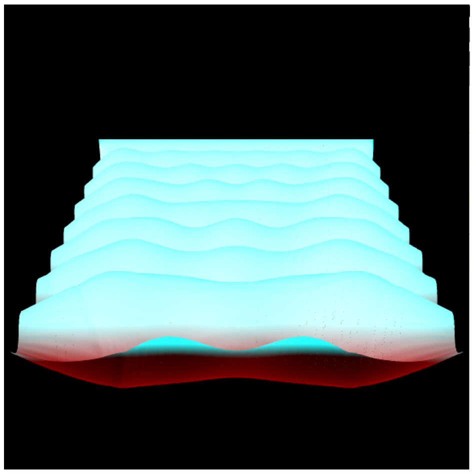

**Figure 4:** 3D simulation, frequency 2 Hz, side border effect, no damping.

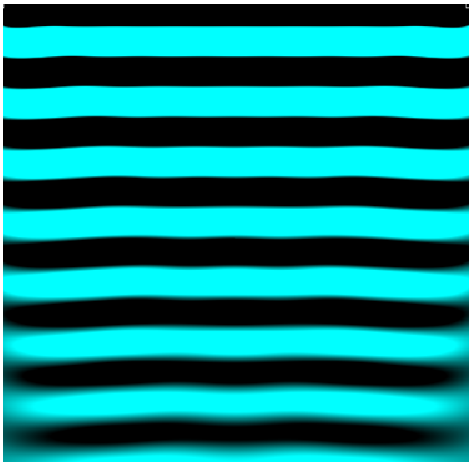

**Figure 3:** 2D Simulation, frequency 2 Hz, side border effect, 35% damping

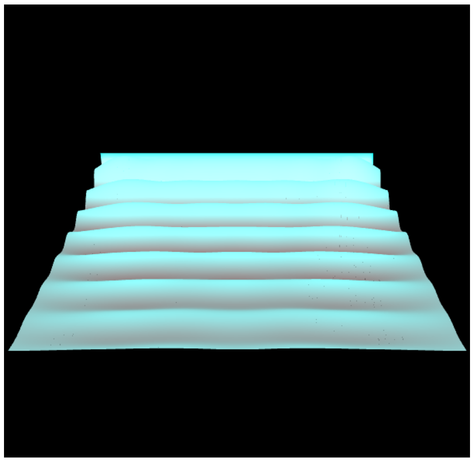

**Figure 5:** 3D simulation, frequency 2 Hz, side border effect, 35% damping.

Experimental setup for the measurement of long waves could consist of pressure transducers; capacitance-types wave gauges or ultrasonic probes [15]. These sensors should be placed: a) at the generating region so that incident wave conditions can be detected, measured and calibrated; b) at the working region in order to estimate the long waves; c) at the bottom region in order to evaluate any transmitted waves.

Setup for ripples measurement should include an optical system, equipped with video-recording cameras placed within the working zone, and a suitable image post-processing software.

An anemometer could return the airflow speed, knowledge of which will be essential to appropriately adjust the fan.

## 3. Numeric Simulation

Numerical simulation was carried out through *Ripple Tank Simulation Software of Saint Olaf College*.

Thanks to a wave generation simulator, it allowed analysing effects of two-dimension waves, including such wave phenomena as interference, diffraction (single slit, double slit, etc.), refraction, resonance, phased arrays and Doppler effect.

The simulator is able to reproduce different source types: point-like, plane, multiple etc. The simulator allows then establishing:

- Source types (point, multipoint, plane, half plane, array, etc.)
- Wave types (mechanical, radio, micro-waves, etc.)

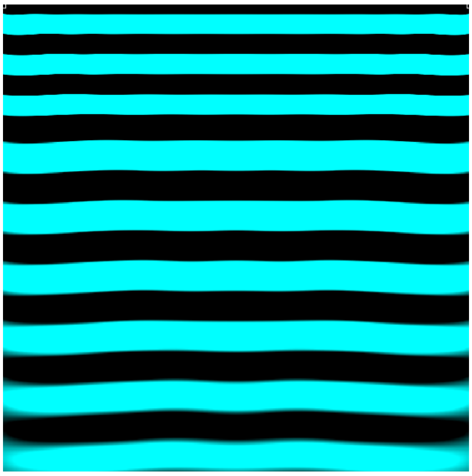

**Figure 6:** 2D Simulation, frequency 3 Hz, side border effect, no damping.

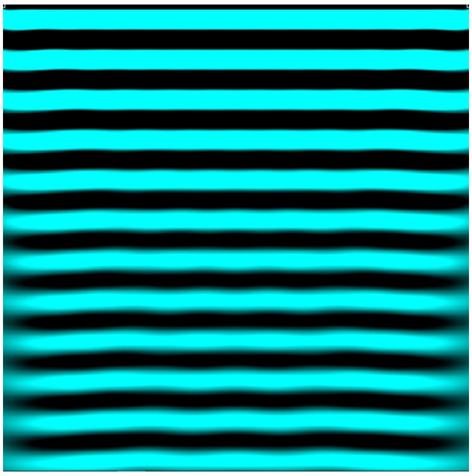

**Figure 7:** 2D Simulation, frequency 3 Hz, side border effect, 35% damping

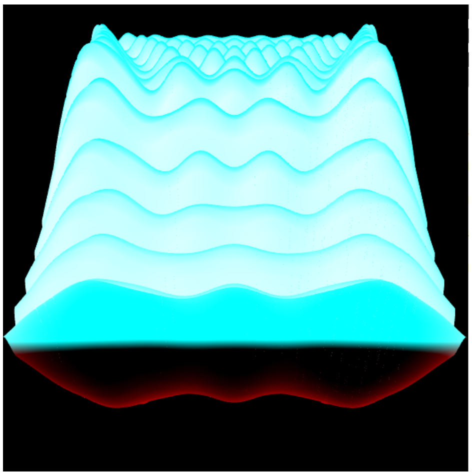

**Figure 8:** 3D simulation, frequency 3 Hz, side border effect, no damping.

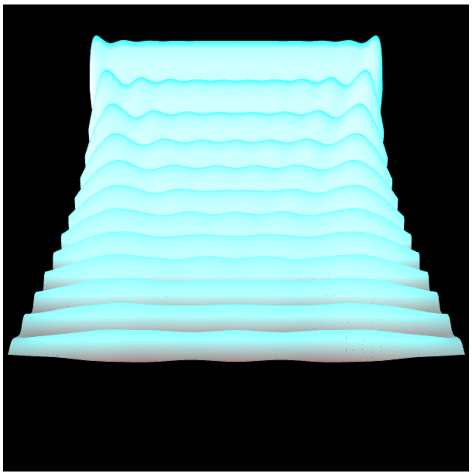

**Figure 9:** 3D simulation, frequency 3 Hz, side border effect, 35% damping.

- Simulation speed (works in real time or at accelerated speed)
- Target frequency (0-5 Hz)
- Percentage of energy damping on the bottom surface of the tank (0-100%)
- Obstacle types: Wall, Slit, Box, Point source, Line source, Multipole source, Phased array Source, Solid box, Moving Wall, Moving Source, Cavity, Medium, Mode box, Gradient, Ellipse, Prism, Ellipse Medium, Parabola, Lens, Probe.

The simulator also took into account side edge effects of the tank.

In this study, a plane wave source was chosen having the same width of the entire tank so to generate waves in the direction of propagation along the major axis. This allowed designing such a width that the central part of the waves was not affected by side edge effects.

A working length ranged between 1000 and 2500 mm from the wave-maker was identified (appropriately far from both the source and the target), within which the waves were not significantly perturbed by the effect of the generator and dampers.

It was therefore possible to identify the amount of energy dissipated during the impact with the back wall constituted by the dynamic dampers.

Simulations were carried out with frequencies ranging between 1 and 3 Hz. For each of these frequencies damping parameters were identified as functions of the geometry of the applied damping device.

Examples of long wave simulations at frequencies of 2 and 3 Hz respectively as well as the corresponding damping percentages are shown in Figs. 2-9.

# 4. Conclusion

In this paper, the model of a water shallow tank for long and capillarity waves was proposed. Numerical simulations, carried out at design values of the most significant parameters, ensured that the central part of the waves was not affected by side edge effects. Also the working zone was demonstrated to be not perturbed by the wave-maker, the blower and dampers.

The future goal is to build such a tank, which seems suitable for various engineering applications on the motion of fluids. In particular, the water tank will be used to experimentally verify and validate a floating spar buoy designed by the authors in a previous study.

# References

[1] H. Akyildız, N. E. Ünal, Sloshing in a three-dimensional rectangular tank: numerical simulation and experimental validation, Ocean Engineering 33 (2006) 2135–2149.

[2] N. G. Jacobsen, D. R. Fuhrman, J. Fredsøe, A wave generation toolbox for the open-source cfd library: Openfoam®, International Journal for numerical methods in fluids 70 (2012) 1073–1088.

[3] P. Higuera, J. L. Lara, I. J. Losada, Realistic wave generation and active wave absorption for navier–stokes models: Application to openfoam®, Coastal Engineering 71 (2013) 102–118.

[4] J. A. Armesto, R. Guanche, A. Iturrioz, C. Vidal, I. J. Losada, Identification of state-space coefficients for oscillating water columns using temporal series, Ocean Engineering 79 (2014) 43–49.

[5] W. Finnegan, J. Goggins, Numerical simulation of linear water waves and wave–structure interaction, Ocean Engineering 43 (2012) 23–31.

[6] C. Windt, J. Davidson, J. V. Ringwood, High-fidelity numerical modelling of ocean wave energy systems: A review of computational fluid dynamics-based numerical wave tanks, Renewable and Sustainable Energy Reviews 93 (2018) 610–630.

[7] S. Mayer, A. Garapon, L. S. Sørensen, A fractional step method for unsteady free-surface flow with applications to non-linear wave dynamics, 1998.

[8] P. A. Madsen, H. Bingham, H. Schäffer, Boussinesq-type formulations for fully nonlinear and extremely dispersive water waves: derivation and analysis, Proceedings of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences 459 (2003) 1075–1104.

[9] A. P. Engsig-Karup, J. S. Hesthaven, H. B. Bingham, P. A. Madsen, Nodal dg-fem solution of high-order boussinesq-type equations, Journal of engineering mathematics 56 (2006) 351–370.

[10] D. R. Fuhrman, P. A. Madsen, H. B. Bingham, Numerical simulation of lowest-order short-crested wave instabilities, Journal of Fluid Mechanics 563 (2006) 415.

[11] A. Kamath, H. Bihs, Ø. A. Arntsen, Numerical modeling of power take-off damping in an oscillating water column device, International Journal of Marine Energy 10 (2015) 1–16.

[12] Q. Chen, D. M. Kelly, J. Zang, On the relaxation approach for wave absorption in numerical wave tanks, Ocean Engineering 187 (2019) 106210.

[13] A. Zavadsky, L. Shemer, Measurements of waves in a wind-wave tank under steady and time-varying wind forcing, JoVE (Journal of Visualized Experiments) (2018) e56480.

[14] G. B. Arfken, D. F. Griffing, D. C. Kelly, J. Priest, chapter 8 - mechanical waves, in: G. B. Arfken, D. F. Griffing, D. C. Kelly, J. Priest (Eds.), International Edition University Physics, Academic Press, 1984, pp. 344 – 360.

[15] S. Sternini, A. Quattrocchi, R. Montanini, A. Pau, F. L. di Scalea, A match coefficient approach for damage imaging in structural components by ultrasonic synthetic aperture focus, Procedia engineering 199 (2017) 1544–1549.