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ARTICLE

Coastal Pumped Hydroelectric Energy Storage: A Variable Volume Floating Tank Design for the Lower Reservoir

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ABSTRACT

An innovative freshwater storage tank design is considered the key element of the lower reservoir for coastal pumped hydroelectric energy storage (PHES) plants. The cylindrically shaped open-top tank is constructed entirely of recyclable plastic materials; it floats on the sea surface and has flexible walls and a bottom that is impermeable to seawater. The design incorporates a retractable wall that allows for a variable volume capacity of the tank, and as such, it expands and retracts just like a concertina. The lower reservoir is envisaged as modular construction, comprising an array of floating tanks, connected and anchored at the bottom of the sea by a grid mooring system, not unlike those used in coastal fish farms. In fact, a great deal of aquaculture technology has been adopted in the present design, and components like the cage collar (float), sinker tube, connecting grid and mooring systems are the same as those used for decades in fish farming. Key considerations such as modularity, construction costs, installation time, environmental impact, flexibility, and recyclability led to the adoption of this innovative solution, as the lower reservoir of coastal PHES plants uses fresh or desalinated water. As proof-of-concept, a fully functional scale model of the tank was built and assessed in real-life coastal conditions, with results that not only met but also proved to be beyond the author's expectations. The proposed design concept, fabrication of the tank model, tests performed, experimental data and their evaluation are described in detail. Finally, future work is suggested.

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1. Introduction

Given the immediate need to store electricity produced from RES and to address water scarcity, it is proposed to build a floating desalinated water reservoir in coastal areas, with walls made of impermeable plastic film, which will be able to fold, essentially forming a bag of variable capacity. Key issues such as modularity, construction costs, installation time, environmental impact, flexibility and recyclability led to the adoption of an innovative solution for a PHS pilot plant based on an underwater desalinated water tank. Most of this technology exists in offshore fish farming. These are cylindrical fish cages, a technology that has been used for years and continues to evolve. These cages are almost entirely made of plastic. The only thing that should be done is to replace the net with an impermeable film.

This innovative technology makes it possible to develop a modular system for the project's downstream PHS reservoir in record time with the possibility of adjusting its capacity to address the evolution of the energy storage needs during its planned operation, without land commitment or environmental impact, since it is based on the use of storage units made of recyclable materials, which can be repaired or replaced at any time required without the interruption of the project! Recently, the tests of a 1:5 scale model of a marine collapsible desalinated water tank were completed. An array of such tanks, which in their natural dimensions will have a capacity of 10,000 m^3 of desalinated water, will compose the downstream reservoir (onshore) PHS unit. The tests were preceded by an evaluation of conventional and non-contractual solutions to the problem of the offshore reservoir, as well as a preliminary design of the natural dimensions of the reservoir, which includes the cost of construction and installation.

The tests included the pump, piping for filling/discharging the reservoir, as well as supporting equipment such as a crane for launching/lifting, etc. The aim of the tests was the proof-of-concept of the collapsible sea tank, and particularly its controlled folding during discharge, as well as its hydrostatic behaviour during filling. Three configurations of the tank were tested with decreasing aids to control its folding. The tests did not include hydrodynamic (wave or underwater current) or aerodynamic loads since they were conducted in a port. The experiment was a complete success, proving that the idea of a flexible collapsible tank made only of plastic materials for storing desalinated water in the sea is feasible. The cost of construction and installation of such a tank, with a capacity of 10,000 m^3 is estimated at 120,000 euros, i.e., twelve euros per cubic meter of desalinated water. The filling/emptying of the tank was performed with absolute success from above only (free tank surface), making filling from below (bottom) unnecessary. This translates to a single pipe for each floating tank of the lower reservoir, which in turn means a simpler layout, hassle-free operation, and lower costs.

Pumped hydroelectric energy storage is the overwhelmingly established bulk electrical energy storage technology, with a global installed capacity of around 130 GW and has been an integral part of many markets since the 1960s [1–3]. In a typical plant, the lower reservoir receives water from the turbine discharge (**Figure 1**). When the system is in power generation mode, for example during high demand, the lower reservoir receives water. When power supply to the grid is in excess (during low-demand periods or from renewable energy sources, since we cannot stop the sun or the wind), the PHES switches to pumping mode, with the pump's suction receiving water from the lower reservoir.

Many islands meet the above conditions, experiencing big variations in population due to tourism and, at the same time, renewable energy installations [4,5]. Coastal PHES, utilizing the sea as a lower reservoir, have been applied several times in the past on islands [6]. One characteristic example was the Okinawa Yanbaru coastal PHES plant (**Figure 2**), with a capacity of 30 MW, on the island of Okinawa, Japan [7].

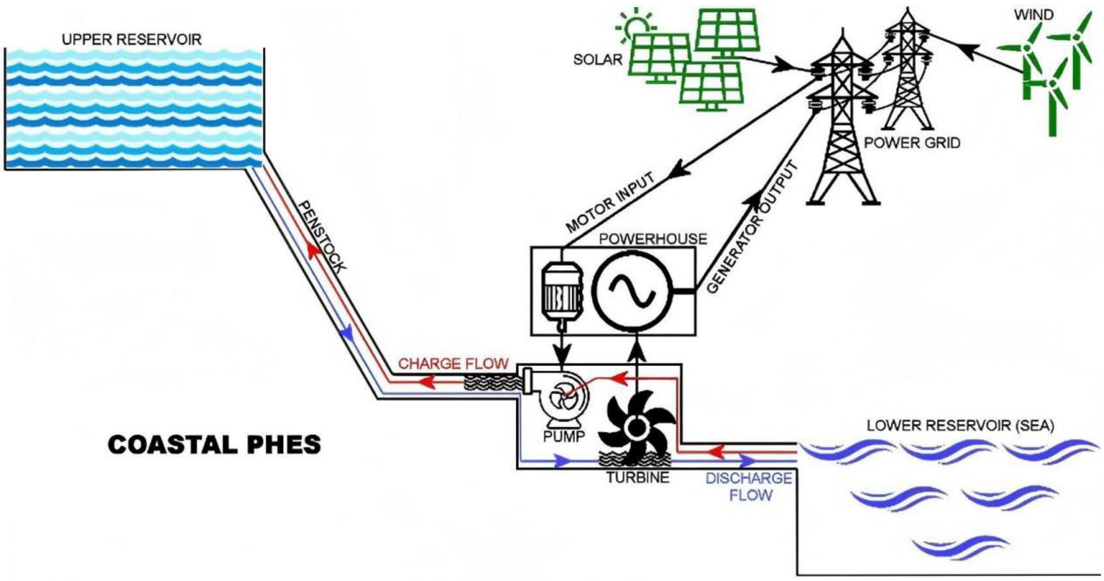


Figure 1. A typical configuration of a coastal PHES plant.

Figure 2. Okinawa Yanbaru coastal PHES plant, 30 MW capacity.

Using the sea as a lower reservoir necessitates the use of stainless-steel components for turbine/pump components to extend life and reduce equipment corrosion [8]. This can be avoided if fresh or at least desalinated water is used. Introducing a desalination plant in such a project would also alleviate water scarcity and drought problems that many islands face, especially during the high season. This would necessitate the lower reservoir being isolated from seawater [9,10].

In favor of environmental impact, recyclability, installation time, construction costs, reusability and scalability, the authors came up with an unconventional lower reservoir design comprised of individual, variable volume, floating tanks made of 100% recyclable plastic materials. The concept of an underwater liquid containment system is not new, as Swigger [11] envisaged one that would look like an elongated stock-like closed container, immersed in a body of water. Hadjerioua et al. [12] went several steps further by modifying the sidewall to be vertically collapsible, making it of variable volume, with guides anchored on the seabed. They also added pontoons to make it float and applied the system to PHES as its lower reservoir. The authors capitalized on existing coastal aquaculture technology by utilizing 95% of components from it for their own concept of a variable volume, floating tank. Essentially, the only part that is different is the fish net, which is replaced by a vinyl-coated polyester tarp, a flexible, strong and sustainable material that is extensively used in architecture. One major difference to the Hadjerioua concept is that the retractable wall of each tank is not anchored through guides to the seabed. Instead, a sinker tube is used for stabilization [13]. Individual tanks are connected in a grid that is anchored to the seabed via a mooring system, very similar if not identical to coastal fish farm grid and mooring systems.

The present study illustrates the conceptual design of a variable volume floating tank as the key element of the lower reservoir of a coastal PHES plant. The project was triggered and funded by the Greek Ministry of Environment, Energy and Climate Change to address the problems of power management and water scarcity in the Aegean islands.

This manuscript is structured as follows: The proposed design concept and the fabrication details, such as the chosen shape and materials of a 1:5 scale model of a 10,000 m^3 capacity tank, are described in Section 2. Three tests concerning charging and discharging the tank under various configurations are also described in this section. In Section 3, the test results are described, while in Section 4, a discussion on the test results, including their validation, is offered. Finally, conclusions drawn from this experimental research work as well as suggested future work are presented in Section 5.

2. Materials and Methods

2.1. Design

An example pilot PHES plant, suited for one of the less populated Aegean islands, would provide 5 MW of storage capacity if a 200 m head could be secured close to the coast. The resulting volume of water necessary for such an installation would be 235,000 m^3, which should be the requirement for the minimum volume capacity of the lower reservoir. This is of a modular form, comprised of 10,000 m^3 units, a floating tank farm, so to speak. It would require 24 variable volume tanks, tied together to form an array and moored to the seabed (**Figure 3**), not much differently than in a typical coastal fish farming plant [14].

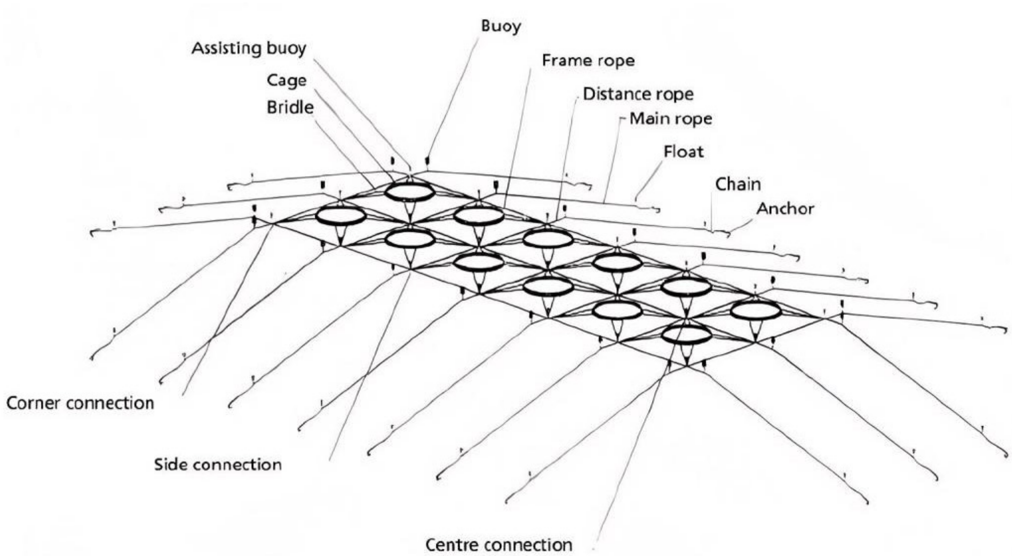


Figure 3. A typical coastal fish farming plant grid mooring system.

Source: Courtesy of POLARCIRKEL, Norway.

A 10,000 m^3 tank is by no means restrictive to the design. It can be scaled up or down depending on the economics of the project, if scaling is within the limits of the current aquaculture technology, which the proposed design borrows many components from.

Choosing a cylindrical shape with a radius-to-draft ratio equal to 1, the tank should have a radius of 14.71 m. After rounding this to be ⌀30 m, the draft of the tank becomes 15 m, and its maximum volume capacity is 10,603 m^3. Rounding the diameter helps in using off-the-shelf standardized components of the fish farm industry, like for example floating collar(s) (**Figure 4**). The proposed variable volume floating tank is in all senses identical to a fish cage, except for the net. The net is replaced by a water-impermeable, flexible membrane that is constructed from vinyl-coated polyester fabric, a material commonly used for making tarp covers and architectural structures like canopies and even walls. PVC and PVDF-coated polyester fabric is made up of a polyester scrim, a bonding or adhesive agent, and an exterior PVC coating (**Figure 5**).

Figure 4. Typical circular floating collar(s), constructed of high-density polyethylene (HDPE).
Source: Courtesy of GESIKAT Ltd., Greece.

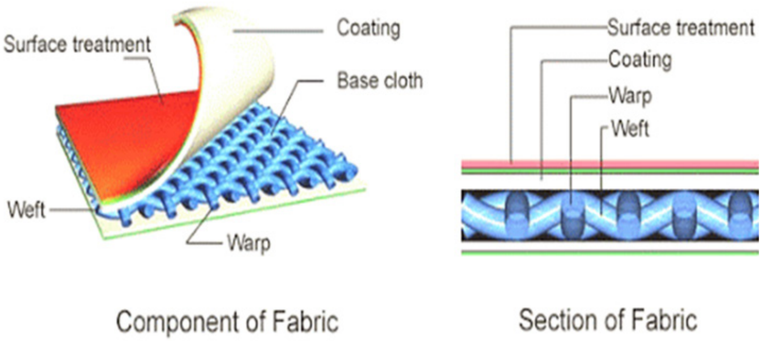


Figure 5. Typical layer construction of PVC-coated polyester fabric material [15].

Over the last two decades, these technical membranes have undergone significant advancements [16,17]. One of the most notable advancements in PVC-coated polyester fabrics is the substantial increase in durability and longevity. In the present application, sustainability is of paramount importance and although there was much controversy in the past, these fabrics are now considered eco-friendly and are free from harmful chemicals like phthalates and heavy metals. This allowed them to be used in architectural structures, like stadiums and many other types of buildings, where fire retardant properties are also important, although not in our application. Additionally, recycling programs have significantly expanded, making it easier to repurpose and recycle materials, reducing the environmental impact of these products.

For constructing the flexible wall and bottom of the tank, a polyvinyl chloride (PVC)-coated polyester tarp was selected with a weight of 1,356 kg/m^2 and a thickness of 1.07 mm. Although its strength and durability are undisputed, the tarp forming the wall and bottom of the tank is in fact sustaining minimum lateral loads, since inside and outside pressures are equalized. Lateral loads on the tank wall will be basically coastal underwater or sea surface currents, which do not fall within the scope of this paper. Based on the final 10,000 m^3 tank dimensions (**Figure 6**), the wall has an area of 1,414 m^2 and the bottom 707 m^2, totaling 2,121 m^2 of tarp. Vinyl-coated polyester tarp is produced in rolls that can be up to 3 m wide and up to 50 m long. These can be seamed together by either chemical or thermo-mechanical means.

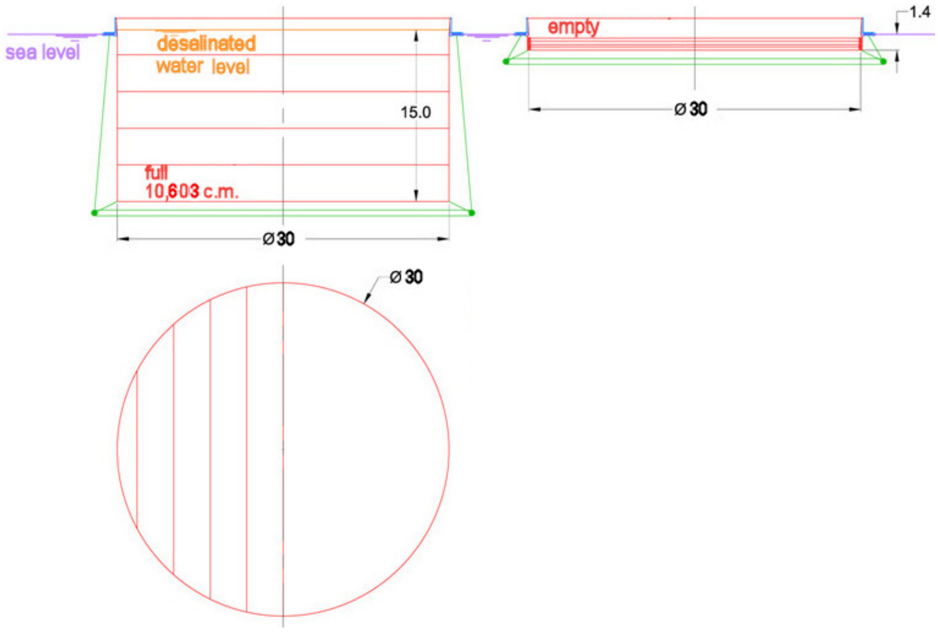


Figure 6. Conceptual drawing of a 10,000 m^3 variable volume floating tank for storing water in coastal areas.

Other key components of the floating tank are: (a) the floating collar(s), mentioned earlier (**Figure 4**), (b) the sinker(s), (c) the grid system, (d) the mooring system and finally, (e) a network of rope lines and loops for tying everything together. Secondary components are: (a) wall reinforcements, (b) bottom reinforcements, and (c) power winches for lifting the sinker(s). All the key components are also key components of fish cages in coastal aquaculture technology and as such are directly or with minor modifications applied to the proposed tank design.

The floating collars in this case are two (**Figure 4**), as used in balanced circular cages for additional stability, consisting of two ⌀0.315 m hi-density polyethylene (HDPE) pipes filled with 20 kg/m^3 polystyrene. This pipe is looped and connected at the ends to form a circular ring with enough circumference to include the circumference of the tank, calculated to be 94.25 m. A single ⌀0.110 m HDPE pipe is used as a handrail, and two of the same are placed between the floating collars to form the support for the deck panels. All these are connected by several L-shaped brackets called stanchions, of the same material. The top rim of the open-top cylindrically formed tarp is suspended from the stanchions (**Figure 6**), via proper support, loops and synthetic rope. The sinker, in this case of the sinker tube type, is a single ⌀0.315 m HDPE pipe filled with ballast material, like anchor chain, wire rope or even rubble. The rim of the bottom of the cylindrically formed tarp is connected to the sinker tube, which, as the name suggests, sinks and keeps the walls as vertical as possible (**Figure 6**) under calm but also under adverse environmental conditions. All these components are constructed from HDPE, a fully sustainable material used in fish farming for decades.

The way the tank operates is, when filled with desalinated water, its bottom and sinker tube sink, dragging with them and deploying the wall, until the draft becomes 15 m (**Figure 6**, right). As the tank is emptied, buoyancy (or external pressure) will push the bottom to the sea surface, retracting the wall and folding it, like a concertina (**Figure 6**, left). Secondary components are structural reinforcements in the form of rings, also made of HDPE pipe, that assist in the tank wall retaining its cylindrical shape and the bottom retaining its flatness as it is being charged/discharged. There is also a series of power winches, attached circumferentially to the deck of floating collars, that assist in retracting the wall by lifting the sinker tube, while the tank is being emptied. These are also components used in coastal aquaculture technology, but in that case to lift fish cage nets for maintenance or replacement. Investigating the necessity of these secondary components is one of the goals of the following tests.

Direct and easy access to the waterfront and good protection from wind, waves, and underwater currents were the main criteria for selecting the site for these tests. When choosing the installation location of the lower reservoir of a PHES plant, the prevailing weather and underwater conditions should be considered, as described in detail in the Norwegian regulation NS9415 [18]. Site-related prevailing weather and underwater conditions are of a statistical nature, as has been demonstrated by Kardakaris et al. [19]. There is a strong variability in weather conditions, with surface waves estimated to vary due to diurnal and seasonal periodicity, appearing in sequential clusters of highs.

Effects of variable weather conditions on the behavior of floating HDPE fish cages, as used in aquaculture, have been extensively investigated in the past. Cheng et al. [20] and Mjåtveit et al. [21] used numerical modeling to predict the effects of strong underwater currents on the behavior of gravity-type fish cages. Faltisen and Shen [22] have extended computer modeling of fish farms to include loads from extreme surface wave conditions, where hydroelasticity can play a significant role for net cages and closed membrane-type fish farms. Shen [23] completed his philosophical dissertation on the subject, performing a very detailed computational analysis on the operational limits of floating-collar fish farms in underwater currents, as well as regular and irregular surface waves. Theoretical and computational model results were compared to experimental investigations on realistic fish farm models. FAO (Fish and Agriculture Organization) of the United Nations [14] as well as the Norwegian Standards NS9415-2003 [24], on Marine fish farms requirements for site survey, risk analyses, design, dimensioning, production, installation and operation, are proposing site classifications based on environmental parameters like depth, shelter (waves), sea bed, current, fouling and pollution. As an example, the standard [24] proposes a site classification based on wave classes ranked from A to E, A being sheltered sites (wave height 0–0.5 m, period 0–2 s) and E being very exposed off-shore sites (wave height > 3 m, period 5.3–18 s).

Although all the above prior research, standards and regulations are applicable to aquaculture technology, there is the extreme case of fish nets rendered impermeable to seawater due to severe biofouling, which is the accumulation of calcareous marine organisms. This extreme case is examined by the above studies and is included in the drafting of the above standards and handbook. As such, grid and mooring systems, anchoring and floats are proposed and regulated by these standards to face extreme impermeability, wave, current and tidal conditions. Such systems will be applicable to the proposed impermeable floating tank and although not within the scope of the present paper, are covered by the Norwegian regulation standard and FAO handbook, which will be used as guides for a complete study of a pilot PHES lower reservoir tank farm.

The total surface area covered by the lower reservoir's 24 floating tanks is approximately 17,000 m^2. To prevent evaporation and exploit this acreage, it is proposed that each open-top tank is covered by floating solar panels [25].

Additional details on the parts and components of the floating tank are provided in the following section, where a fully functional scale model of the 10,000 m^3 variable volume floating tank is constructed and tested. Construction costs and installation time are comparable to coastal fish farm facilities, whereas the materials used ensure that the lower reservoir is scalable and entirely recoverable, resulting in zero environmental impact upon decommissioning, including the removal of the grid and mooring systems.

2.2. Scale Model

Feasibility, functionality and manufacturing methods for the proposed variable volume, floating tank were proven by designing, building and testing a scale model. The tank used for the tests was an exact replica of the 10,000 m^3 water tank discussed in the previous section, but down to 1:5 scale. Overall dimensions of the scaled-down tank when fully deployed were ⌀6 m, with a draft of 3 m and a circumference of 18.85 m (**Figure 7**). Maximum volume capacity achieved at full wall deployment was 85 m^3. Floating collars were also scaled down, to the capabilities of the manufacturer, to ⌀0.110 m HDPE pipe, while the handrail was made of ⌀0.075 m HDPE pipe (**Figure 8**).

Three ⌀0.063 m HDPE tubes formulated the deck and added stiffness to the floating collar assembly. A total of 18 stanchions (L-shaped brackets) were used to hold the floating collars, handrail and deck tubes together in a circular shape. Due to their relatively small size, compared to what the aquaculture industry is used to, they had to be machined from HDPE solid plate (**Figure 9**). The sinker tube was made of a ⌀60.3 mm galvanized steel tube, bent into a ring. Its weight was calculated so it was not necessary to fill it with ballast.

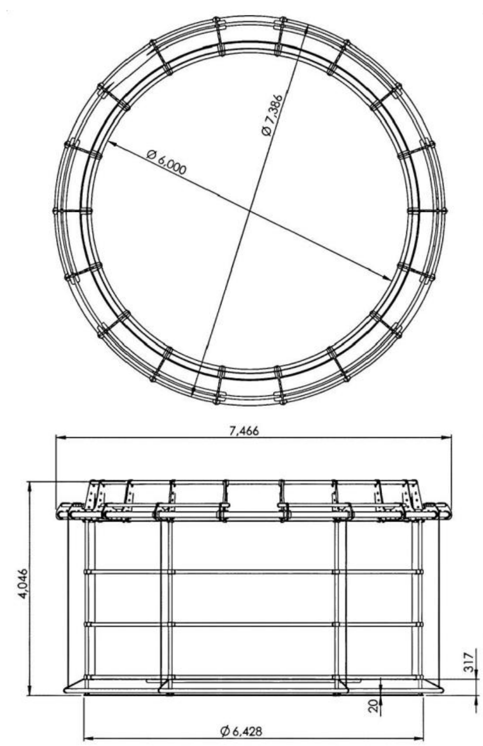


Figure 7. Overall dimensions of the 1:5 scale model of the 10,000 m^3, variable volume floating water tank.
Source: Courtesy of GESIKAT Ltd., Greece.

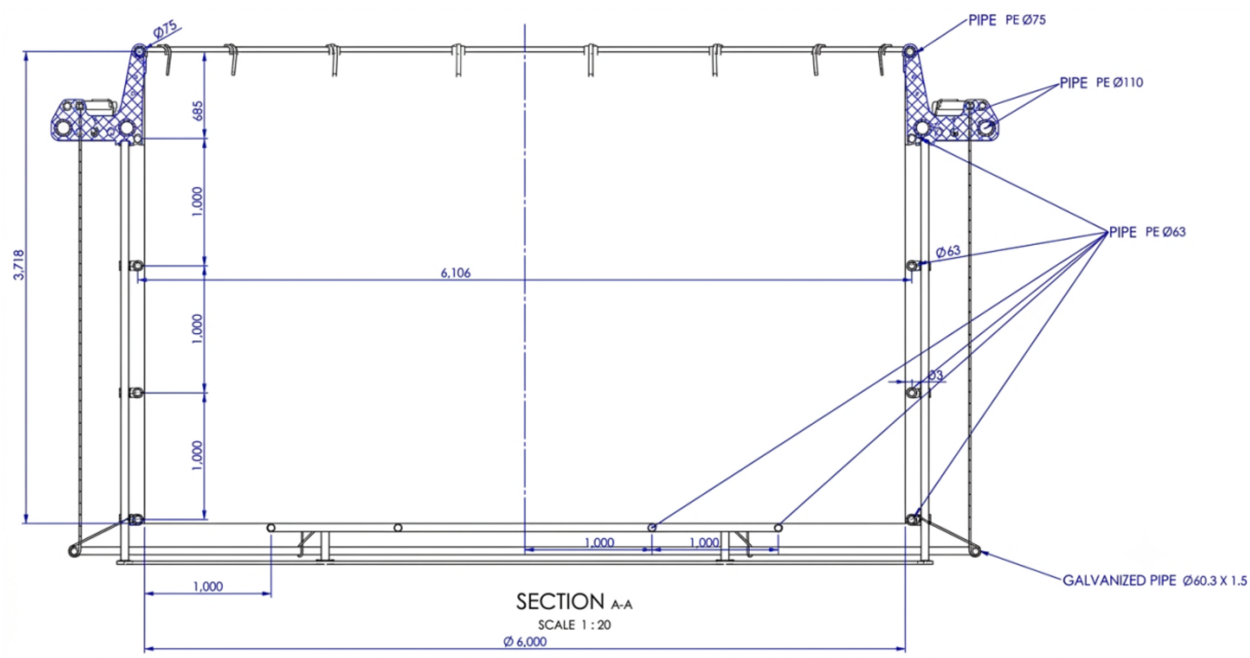


Figure 8. Cross-section of the scale model of the tank.
Source: Courtesy of GESIKAT Ltd., Greece.

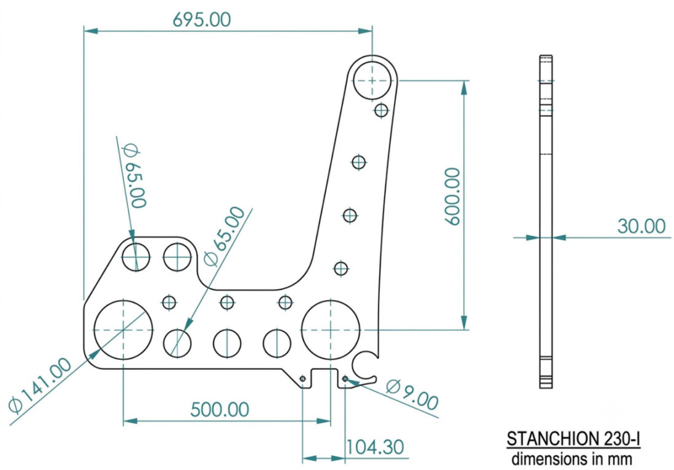


Figure 9. Detail of the stanchions (brackets) used for manufacturing the scale model.

Source: Courtesy of GESIKAT Ltd., Greece.

The wall and bottom of the scale model were manufactured of PVC-coated polyester tarp of weight and thickness very close to those of the natural scale tank. This was due to the immediate availability of the tarp to the manufacturer, who was a subcontractor to the floating collar manufacturer. As it turned out to be, to the surprise of the authors, PVC-coated polyester traps are used in the coastal aquaculture industry to contain a fish cage when fish are being treated with medicines, diluted in the cage water.

HDPE tubing of ⌀0.063 m diameter was bent to form 4 rings that were incorporated in the wall at equal vertical intervals of 1 m (**Figure 8**), through specially designed pockets. The main purpose of these reinforcing ribs is to ensure that the tank retains its cylindrical shape during the charge/discharge process.

The bottom was also reinforced with 2 concentric ribs of the identical design (**Figure 8**). The purpose of those was to ensure that the bottom remains as flat as possible, again during the tank's charge/discharge process.

The wall reinforcing ribs were equipped with brackets that slide along 6 vertical guides made of ⌀60.3 mm galvanized steel tube (**Figure 10**). The primary purpose of these vertical guides was to ensure that the wall reinforcing ribs and the bottom of the tank remain horizontal during charging/discharging.

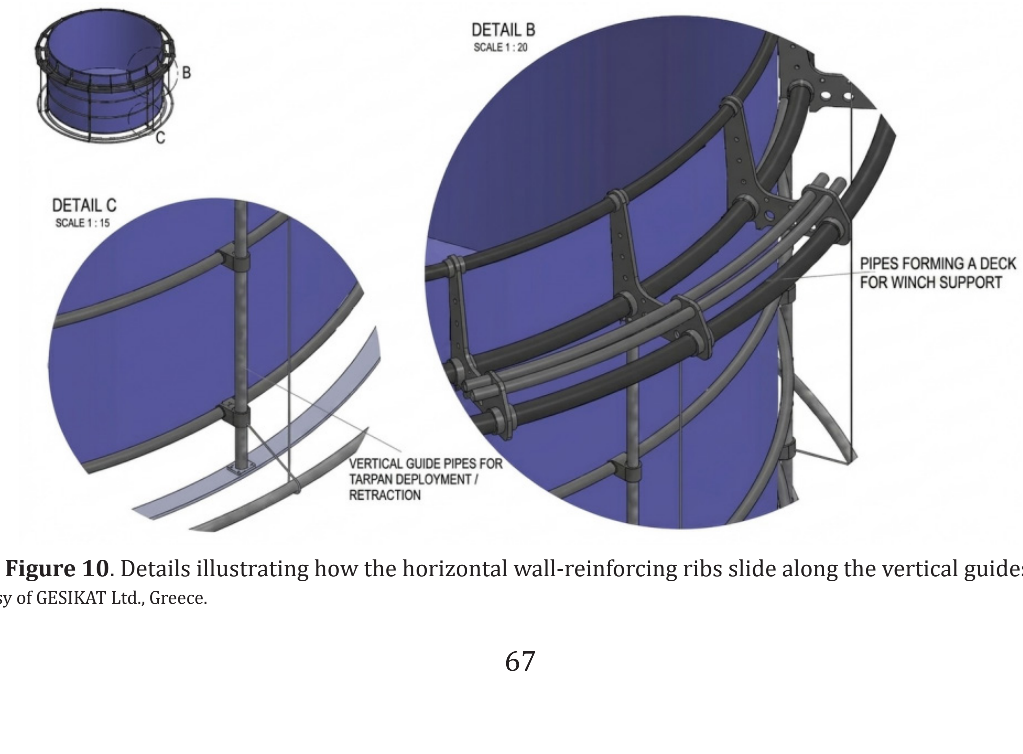


Figure 10. Details illustrating how the horizontal wall-reinforcing ribs slide along the vertical guides.

Source: Courtesy of GESIKAT Ltd., Greece.

Final design, manufacturing of individual parts, assembly and preliminary functionality tests of the scaled-down tank were performed at G.E.SIKAT Ltd. facilities in Levadia, Greece. Only the PVC-coated polyester tarp was manufactured by a subcontractor situated in the vicinity and transferred to G.E.SIKAT for final assembly. It is noted that, although some components were made of galvanized steel due to scale issues, all components of the natural scale tank will be made of fully recyclable HDPE.

The scale model was assembled and disassembled onsite to identify possible issues. It was also dry-tested, with reinforcing ribs and guides on and off, to ensure problem-free deployment/retraction of the wall. Three modes of the tank were thus envisaged for subsequent tests at sea: a) mode 1 (**Figure 11**), having all reinforcing ribs and rib vertical guides installed, b) mode 2 (**Figure 12**), having the 6 vertical guides removed and the sinker tube installed in their place and c) mode 3 (**Figure 13**), having all wall reinforcing ribs removed, but retaining the sinker tube and bottom reinforcing ribs.

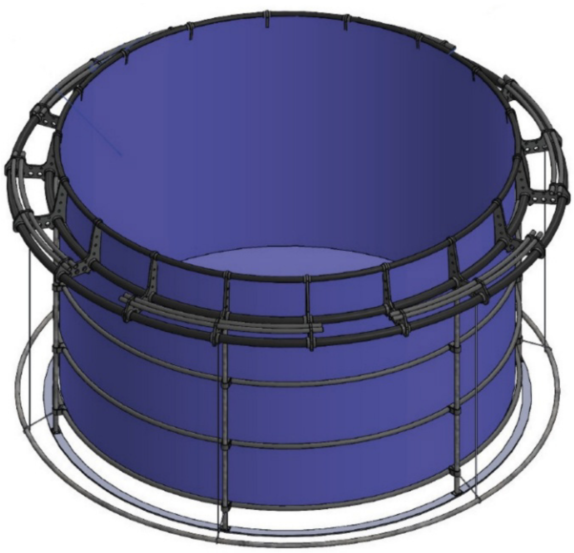


Figure 11. 3D computer model of mode 1 of the scaled-down tank, with all wall and bottom reinforcing ribs and vertical rib guides present.
Source: Courtesy of GESIKAT Ltd., Greece.

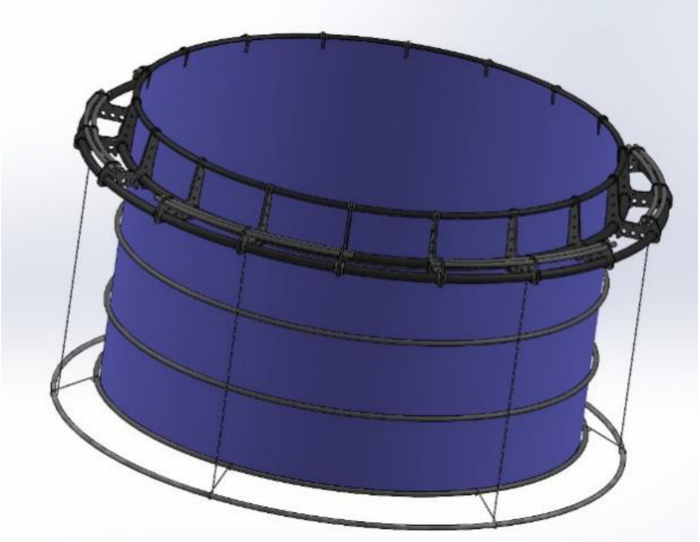


Figure 12. Computer model of mode 2, with vertical rib guides removed.
Source: Courtesy of GESIKAT Ltd., Greece.

Figure 13. Mode 3 of the tank at the test location, the simplest of the three modes where all wall reinforcing ribs and vertical guides have been removed.

The authors and the manufacturer do not see any reason why final assembly and launch procedures of the proposed tank design should be any different from the coastal aquaculture industry standard of doing the same with fish cages. Cages are assembled on a beach, near the fish farm location, launched and tugged, one or more at a time, to the site, where they are attached to the grid and mooring systems. The only difference in the case of 10,000 m^3 floating tanks is that the tarp should probably be assembled on the beach in dry conditions and not at the mooring site in wet conditions, as it is done with fish cage nets.

2.3. Tests

On the morning of the 17^{th} of November 2026, the scale model tank was partially disassembled and, together with all the auxiliary equipment, was transported by truck to the selected test location. The small port of Ag. Nikolaos, roughly halfway between Levadia and Patras, Greece, was selected for the purposes of the test, as shown in **Figure 14**.

Figure 14. Area map of the site selected for testing.

Direct and easy access to the waterfront and good protection from wind and underwater currents were the main criteria for selecting the site.

Three employees of GESIKAT unloaded, assembled and launched the tank into the water with the help of a crane. For the sake of efficiency, it was decided to test mode 1 first and then continue with modes 2 and 3 in that order, as components were being gradually removed, before each launch.

The tank was launched close to the dock to be within reach of the charging/discharging piping (**Figure 15**) and remained tethered to the crane for safety reasons. Since this was a proof-of-concept test, no grid or mooring systems were used. The tank was free-floating on the sea surface, under ideal weather conditions.

Figure 15. First day of tests, at the dock of the small port of Agios Nikolaos, in W. Greece.

Note: The picture shows mode 1 of the scale model tank being discharged.

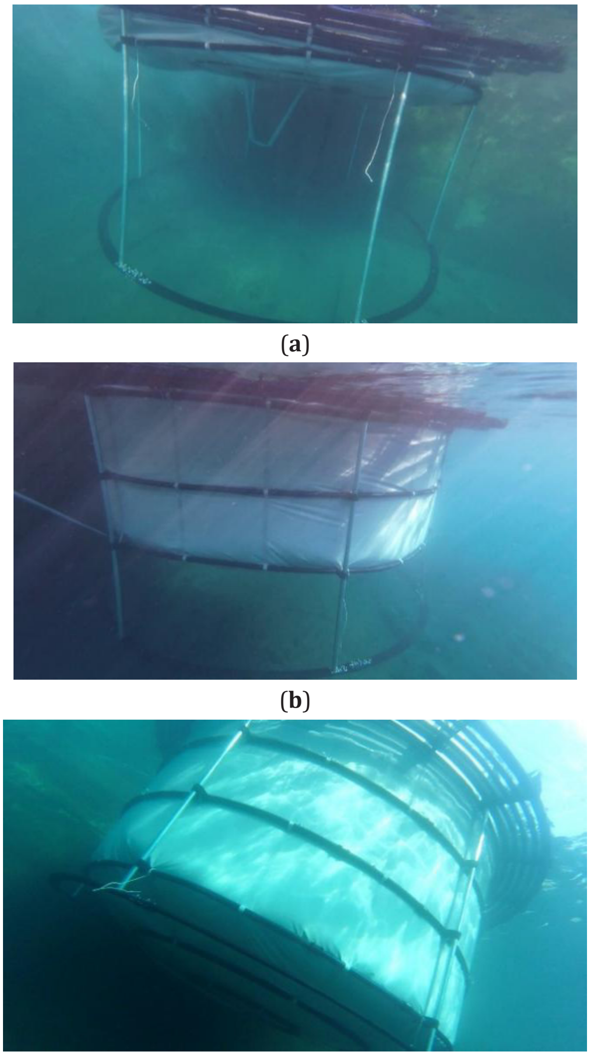
In a PHES plant, the flow rate to the lower reservoir during power generation is much higher than from the lower reservoir during pumping. In general, charging/discharging time of the lower reservoir is a very slow process. To simulate these processes but also shorten test duration as much as possible, the highest-flow-possible pump type was selected. A high-flow, low-pressure diesel irrigation pump was used, with a maximum flow rate of 100 m^3/h. In theory, at least, a full charge/discharge test of the 85 m^3 capacity downscaled tank would take less than 2 h.

All tests were performed using seawater, as fresh water at these quantities would have to be transported to the dock. This had no significant bearing on the test results, as the only visible difference would have been the level of fresh water inside the tank, which would have been a bit higher than the surrounding seawater.

Flexible water hoses, ⌀4.0 in, were connected via quick-release clamps to the suction and discharge of the pump (**Figure 15**). The pump discharge hose was connected to a long-reach, L-shaped steel pipe of the same diameter. The purpose of this was to reach as far as possible from the tank wall while charging the tank. Due to the high flow rates during the test, an improvised, cone-shaped flow diffuser was connected at the end of the steel pipe to prevent damage to the tank bottom when it was empty. All tests were performed by charging and then discharging the scale model tank, from the open top, by simply switching the suction and discharge pump hoses between the tank and the open sea. Tests on the mode 1 tank were initiated in the early afternoon of the 17^{th} of November 2026, only to be concluded with the mode 2 and 3 tanks by late afternoon the next day.

3. Results

An issue that appeared early on, during the charging phase of the mode 1 tank (**Figure 11**) test, was an air bubble trapped underneath the tank bottom as it was lowered on the sea surface. This is something that is bound to happen every time a completely empty variable volume floating tank is launched at sea for the first time. The air bubble is eventually released and the bottom will level out as the tank is filled with water and the latter starts sinking. **Figure 16** illustrates three instances of the mode 1 test. In **Figure 16a**, the scale model tank was filled to about 5% of its maximum volume capacity. The bottom of the tank was almost floating on the sea surface, not level due to the trapped air bubble, whereas the tank wall and reinforcing ribs were almost completely folded as expected to be, just like a concertina.



(**a**)

(**b**)

(**c**)

Figure 16. Underwater snapshots of the variable volume floating water tank (mode 1) at: (**a**) 5% capacity; (**b**) 66% capacity; (**c**) 100% capacity.

As the tank was progressively filled with seawater, the wall was further deployed, maintaining its cylindrical shape, due to the internal water pressure built up and assisted by the reinforcing ribs. **Figure 16b** illustrates the tank at 66% capacity, at which point in time the bubble was completely vented. The tank bottom was submerged by 2 m, seating fully horizontally, as assisted by the vertical guides on which the wall reinforced ribs slide. The wall has been deployed by 2/3, with two ribs clearly visible at 1 m and 2 m depth, respectively. **Figure 16c** shows the tank at full capacity with 85 m^3 of seawater in it. The wall was fully deployed and the bottom was nearly flat and horizontal, forming a nearly perfect cylinder of 6 m diameter and 3 m length. This appears to be the result of the reinforcing ribs (one deployed every meter), but subsequent tests have revealed that the cylindrical shape is mainly due to internal water pressure. At the same time, the vertical guides always kept the tank bottom horizontal.

The tank charging phase started at 14:35 and was completed almost one hour later at 15:30, with the discharging phase of the test following immediately after and lasting almost as long. Surface and underwater observations of mode 1, scale model tank discharge were the same as during the charging phase. The cylindrical shape was always maintained, with the tank bottom gradually rising, completely parallel to the sea surface and the wall retracting and folding as intended, just like a concertina. Day 1 of testing was concluded by lifting the tank off the water, removing vertical guides and adding the sinker tube, in preparation for mode 2 testing the next day.

The mode 2 (**Figure 12**) charge/discharge test was completed late in the morning the next day, lasting roughly two h in total. Just like during mode 1 testing, the bottom of the tank always remained horizontal, proving that the sinker tube, a standard component of circular fish cages used in coastal aquaculture, is a worthy replacement for the 6 mode 1 vertical guides. The tank performance was again nominal, with the wall deployed/retracted during charge/discharge, respectively, maintaining at the same time a nearly perfect cylindrical shape. Right after completing the discharge phase of the test, the tank was lifted off the water and the three wall reinforcing ribs were removed, in preparation for the mode 3 test.

The charging test phase of the mode 3 tank (**Figure 12**) was completed in under an hour, by late noon the same day, with the discharging phase only to conclude late in the afternoon, after a short pause. As the wall was deployed during the charging phase, it took the shape more of an hourglass than a cylinder. Its cross-section at the free surface was circular with a diameter equal to the diameter of the floating collars, whereas its bottom, also of a circular cross-section, had a diameter slightly smaller than the sinker tube. At 100% capacity, though, the shape was cylindrical, proving that it is the internal pressure tank and not the ribs or guides that affect it. The bottom of the tank always remained level during both phases of the test, proving once again the effectiveness of the sinker tube.

4. Discussion—Validation of the Results

The above results concerning the performance of all three modes tested have shown that the variable volume floating water tank design is sound and behaves exactly as intended under hydrostatic loads in favorable environmental conditions. Furthermore, all reinforcing ribs result in the tank always retaining a perfect cylindrical shape, but omitting them simplifies fabrication significantly, even though the wall shape is not ideal. The sinker tube proved to be as effective as the vertical guides in leveling the tank bottom during operations. Reinforcing ribs and vertical guides are not necessary for the optimal operation of the floating tank, but they would unnecessarily increase fabrication complexity and cost. The tank wall retracting electrical winches were not necessary since they were not used during these tests and yet the tank behaved nominally. Finally, charging/discharging the tank from its open surface is feasible with a single desalinated water line.

Evaluating the three different configurations' test results, it is shown that all three served the purpose for which they were designed. They are safe under the hydrostatic loads to which they have been subjected. As for their mechanical equipment, that worked flawlessly and without problems. Of the three configurations, the 2nd is considered to have the most ideal results, while the 1st is the simplest and easiest to build. The result of the tests is that the onshore, collapsible desalinated water tank works exactly as designed. Based on this outcome, an application for a relevant patent has been submitted to the Greek Patent Office.

Under hydrostatic conditions, the only vertical forces are weight and buoyancy. Validation includes verifying that no other steady forces (e.g., surface tension effects that might be significant for small or thin structures, or elastic tensions in a flexible membrane that could affect the buoyant equilibrium) are present or that they are negligible. This is often done by checking that the equilibrium condition holds precisely over a range of loads, with no systematic drift.

The set of experimental results is shown to obey Newton's gravitational law and Archimedes' buoyancy law to within experimental error, and all observed/measured quantities are mutually consistent (e.g., volume from mass matches volume from geometry, incremental loading agrees with hydrostatic stiffness).

5. Conclusions & Future Work

- Based on the results of this study and those of a recent preliminary technical-economic analysis, it is concluded that, under specific, mainly technological, conditions, the use of plastic tanks, floating near the coast, as the lower tank of a pumped storage project, could be economically viable, if combined with the construction of the upper tank near a wind and/or PV farm, so that the pumped storage system also functions as a recipient/warehouse/self-producer (arbitrage) of its electricity cuts park.
- However, the lack of operational (even pilot) experience in such a complex pumped storage project on a commercial scale creates many technical uncertainties and risks, which primarily concern the interconnectivity and interoperability of floating tanks with the rest of the project (supply pipeline, production station, water intake technical work, etc.), and in fact in a corrosive and meteo-

rologically/hydrologically unstable marine environment (waves, variable tank bottom, necessary anchorages, harmonious cooperation of many floating docks, etc.).

- Therefore, there is a need for pilot tests for the whole of a pumped storage project (and not only for the floating tanks), in which tests will be solved, in a tested and technically reliable way, all relevant technical interconnection/interoperability problems. Only then could a business decision be made for the detailed design, development and construction of such a commercial-scale project.

Author Contributions

The core research work, D.E.K.; invented and introduced the technology concept, A.G.Y.; contributed to the experimental verification, D.E.K. and A.G.Y. Both authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

AI Use Statement

The authors declare that no artificial intelligence (AI) tools were used in the preparation of this manuscript.

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