TECHNICAL PAPER

Best Practices for Design and Installation of Geosynthetic Floating Covers

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ABSTRACT

As a result of a growing scarcity of freshwater around the world, reservoirs with geosynthetic floating covers are increasingly being used to retain, store, treat, protect, and distribute large volumes of water. This paper addresses the current best practices in designing and constructing geosynthetic floating covers for municipal potable water and wastewater treatment and storage. This includes important floating cover design requirements for proper floating cover tensioning, buoyancy, ballasting, wind-loads, geometry and the requirements of sumps, troughs, surface water removal and air venting systems requirements. The paper also addresses the lifecycle cost comparisons, economics and sustainability of floating covers as compared to other common structural methods of storing water including above ground tanks and underground concrete reservoirs. Finally, the paper addresses important material selection, testing, and maintenance requirements that help ensure longer-term performance of bottom liner system geomembranes and floating cover materials exposed to chemical disinfectants, UV light, weather, and other material application stresses related to the day-to-day operation of the floating cover.

Figure 1. 350,000 ft^2 - Floating Cover Eagle Rock Reservoir, CA, USA

INTRODUCTION

Geosynthetic floating covers (see **Figure 1**) have been used since the late 1960's when the first CSPE floating covers were installed in Southern California for municipal water applications. Since then, floating covers have been used extensively in many regions of the world for the protection and storage of water. The demand for floating covers has increased because of regulatory requirements and an increased scarcity of fresh water in many regions of the world. Floating covers also provide one of the most economical methods of protecting and storing large volumes of water. The primary function of floating covers is to prevent dirt and debris from contaminating the water being stored and therefore, maintaining water quality. Floating covers also provide an excellent method to control or eliminate evaporation control in reservoirs. Floating covers also lower the amount of disinfectants required helping to reduce treatment costs. There are several different floating cover systems used today for covering reservoirs as discussed below.

APPLICATIONS AND MARKETS

One of the main markets for floating covers is municipal water which includes municipal water districts and private water operators under the control and direction of government agencies. In municipal applications, floating covers are used for both potable water storage and wastewater treatment applications. For potable water applications, floating covers prevent dirt and debris from contaminating the water storage. Floating covers are also used for evaporation control. Properly designed and installed, floating covers can eliminate evaporation losses as a result of warmer air temperatures, wind, relative humidity, and large exposed water surface areas. In wastewater applications, insulated floating covers are often used in colder regions for biological secondary wastewater treatment of lagoons. In this application, modular insulated floating covers are used to insulate the surface of the water to maintain higher water temperatures which further enhances bioactivity for nitrification and associated reduction levels of biological oxygen demand, chemical oxygen demand, total suspended solids.

By eliminating UV light, floating covers also help reduce algae growth in the water. This is important to protect mechanical piping system, water quality and odor control.

In addition to municipal water markets, floating covers are increasingly being used in other markets including oil and gas, mining, agriculture, waste and airports for evaporation control, odor control, fluid dilution prevention, algae control, biogas containment and security of water. **Table 1** (to the right) lists the common applications of floating covers by water type (Gersh 2019).

Water Storage Type	Function
Potable Water	• Eliminate evaporation • Eliminate algae growth • Reduce chlorine dosing & costs • Protect from airborne contaminates • Protection for bird and wildlife contamination • Security of water source
Raw Water	• Eliminate evaporation (salinity increases) • Eliminate algae growth • Reduce chlorine dosing and costs • Protection from airborne contaminants
Recycled Water	• Eliminate evaporation • Eliminate algae growth • Reduce chemical dosing • Odor capture
Wastewater	• Odor capture • Biogas capture • Reduce algae growth • Reduce chlorine dosing
Mineral Processing	• Eliminate evaporation • Eliminate algae growth • Elimination of increased process water inventory with raining in storage pond • Protecting birds and wildlife

Table 1. Floating Cover by water storage applications (Gersh 2019)

ECONOMICS & SUSTAINABILITY

Floating covers provide one of the most economical methods of storing large volumes of water verses the use of above ground tanks or below grade reservoir with structural roof. For example, in 2009 an 18-acre, 244-million-gallon, (923 M liters) water reservoir designed with a RPP bottom liner geomembrane and CSPE geomembrane floating cover was completed for the Upper Chiquita Reservoir owned by the Santa Margarita Water District in Southern California, USA (Mills and Falk, 2013). The overall cost of the Upper Chiquita project including the construction of the earthen dam, installation of the geomembrane liner and floating cover was approximately $53 million dollars, and it took 1.5 years to complete. Based on the cost to construct the reservoir, the average price per gallon of water was $0.22 USD.

In comparison, the Kelly Butte underground concrete reservoir in Portland, Oregon, USA was completed in 2016. The Kelly Butte project involved the replacement of two older 10-million-gallon (3.8 M liters) storage reservoirs, covered by a steel enclosure. These were replaced with a 25 million-gallon (113.6 M liters) underground concrete storage reservoirs with structural roof. The overall cost in the Kelly Butte project was approximately $90 million and 4 years to complete. This works out to a cost of $3.60 USD per gallon (Fraser and Lotufo, 2021).

A recent estimate for the supply and installation of a 4.2-million-gallon (19.1 M liters) welded steel tank system for water storage installed in Texas in 2020 was $4,200,000. This converts to a construction cost of $1.05 per gallon (B. Matchet, Spiess Construction, 2022).

Table 2 below compares the construction cost per gallon for the three project types. Providing the availability of land, floating covers and reservoirs are the most economical method of storing large quantities of water. In mid to large water storage applications, the cost of constructing a reservoir with a floating cover can be under 30% of the cost of a steel tank or underground concrete reservoir. This represents a major capital and lifecycle project costs savings for the owner.

Project Type	Size	Construction Cost per gal (USD)
Upper Chiquita Floating Cover & Earth Reservoir (2011)	244,000,000 gal	$0.23 gal
Kelly Butte, Under Ground Concrete Reservoir (2016)	25,000,000 gal	$3.60 gal
Texas, Above Ground Steel Water Tank (2020)	4,200,000 gal	$1.05 gal

Table 2. Comparison table of construction costs per gallon of water.

Another important benefit of properly design floating covers is their ability to control and eliminate evaporation losses. In hot arid regions, evaporation losses can be substantial and represent a significant cost to owners. As an example, a Texas Water Development Board report showed a maximum annual 2013 evaporation losses of 97.34" (246.8 cm). Figure 2 shows a lighter colored floating cover installed for an oil & gas company in West Texas in 2014 for evaporation control. (Fraser & Killian, 2015).

Earth or concrete lined reservoirs with floating covers can also provide a sustainability advantage to owners and communities. Compared to structural steel and reinforced concrete tanks and below grade reservoirs with structural roofs, geomembrane floating covers provide a lower carbon footprint resulting in reduced greenhouse gases and CO_2 emissions into the environment. Geosynthetics including geomembranes provide a lower embodied carbon footprint versus many other traditional building materials including steel and reinforced concrete. A polyethylene geomembrane has an approximate calculated embodied carbon footprint of 1.7 – 2.0 Kg $C0_2$/Kg (GSI White Paper #42).

DESIGN CRITERIA

Figure 2. Evaporation control floating cover, West Texas, USA

The long-term performance of floating covers requires the floating cover system to be properly designed by an experienced licensed engineer. A project specific engineered design is required for each project. One of the main floating cover systems is the weighted tensioned floating cover also referred to as a defined sump system (see Figures 3 and 4). This system uses a series of strategically located troughs to provide the required tensioning and buoyancy in the floating cover. The troughs are designed to take up the excess floating cover material and tension the floating cover throughout the reservoir fluctuating high and low operating levels. The tensioning is required to support surface loads on the floating cover including ponded rainwater, operations and maintenance personnel, and floating cover appurtenances. Weight tensioned systems use troughs consisting of surface floats and ballast weights. In standard shaped rectangular reservoirs, it is common to use either a central double wye or bottom of slope trough configuration. Irregular shaped reservoirs often require a custom trough configuration and design. The location of the troughs needs to be properly determined based on the expected operating levels and reservoir geometry including reservoir depth, corners, floor, ramps, intermediate benches, and curves within the reservoir. Weighted tensioned floating covers are scalable and can be used on small reservoirs up to very large size reservoirs.

Figure 3. Defined sump cover in operation

Figure 4. Personnel on cover in full operation

An alternative to the weight tensioned floating cover system is a mechanically tensioned floating cover. For mechanically tensioned floating covers, cables are attached to the floating cover that are connected to counter-weights and a pulley system to maintain the floating cover tensioning. The components are housed in individual steel towers located around the perimeter of the reservoir. The steel cables are attached to the floating cover using a reinforced geomembrane strip located near the top perimeter slope of the floating cover as shown in Figures 5 and 6. Tensioned capable systems are normally best used on rectangular shaped reservoirs up to 250,000 ft2 (23,235 sq m) in surface area.

The design of floating covers also requires a rainwater surface removal system. With weight tensioned floating covers, this is normally done with surface dewatering sump pumps in conjunction with the designed floating cover troughs. For mechanically tensioned floating covers, the rainwater removal system consists of a submersible pumps or gravity type drains installed on the floating cover. The rainwater removal system should be designed for two storms and removal rates:

1) 10-year storm, 24-hour rainfall intensity with capacity to remove rainwater 24 hours after the storm has passed, and
2) 25-year storm, 24-hour rainfall intensity with the capacity to remove rainwater 48 hours after the storm has passed.

Figure 5. Tension cable and towers

Figure 6. Tensioned cable system, Greely, CO, USA

Important design considerations involve understanding the geometry and capacity of the reservoir including size, shape, depth, slopes, and all interior hydraulic structures. Operating water levels need to be determined including standard freeboard, high and low water levels, and fluctuation intervals. Inlet and outlet pipe flow rates and their location need to be factored into the floating cover design.

Site conditions also need to be factored into the design including whether the reservoir is a concrete, asphalt, compacted earth, or geomembrane lined. For earth lined reservoirs, the subgrade needs to be properly compacted and prepared. Older concrete reservoirs often require restoration and repair work prior to relining with a geomembrane liner and floating cover. Groundwater levels in reservoirs also need to be determined to be acceptable to prevent geotechnical problems with the subgrade which can impact the liner and floating cover system.

Engineered loads need to be calculated for all associated dead and live loads on the floating cover including trough ballasting. Wind loads need to be factored into the design and potential additional wind ballasting.

The floating cover and geomembrane liner should be anchored continuously around the reservoir perimeter above the overflow operating water level plus applicable freeboard. Proper perimeter anchorage of the floating cover (and geomembrane liner) is required by means of either mechanical anchorage into a concrete curb or an earth backfilled anchor trench.

Various appurtenances are required on most floating cover systems. These include surface vents for release of any entrapped air or gases under the floating cover, access hatches, inflation hatches, dewater sump pumps, textured walkways, access steps, and ladders. These appurtenances need to be properly attached to the floating cover system by means of welding or mechanical attachment following standard geomembrane installation best practices.

A number of industry engineering design standards, guidelines, and reference materials are available for floating covers used for water reservoir applications as listed below.

- AWWA national, Manual M25, *Flexible Membrane Covers and Linings for Potable-Water Reservoirs*
- AWWA national, Standard D130, *Geomembrane Materials for Potable Water Applications*
- AWWA California - Nevada Section, *Reservoir Floating Cover Guidelines*
- ASCE Standard, *ASCE/SEI 7 Minimum Design Loads and Associated Criterial for Buildings and Other Structures*

MATERIAL SELECTION

Material selection process is also an important part of the design process. This includes determining material required mechanical and endurance properties for all materials, including but not limited to, geosynthetics, concrete, metals, etc.

The material selection process in conjunction with a proper floating cover design and installation are the main factors required to ensure the required performance of the floating cover throughout its expected service life. In municipal potable water applications, several material types have been used over the years for floating covers. These include Chlorosulfonated polyethylene (CSPE), Reinforced polypropylene (RPP), PVC based Interpolymer alloy (EIA), Linear Low Density Polyethylene (LLDPE) and other specialty polyolefin alloy materials. The industry has experienced some inconsistency and performance problems with certain of these materials primarily in municipal potable and wastewater applications. For this reason, it is important for owners and engineers to carefully research their material selection. The material selection process should include ensuring the material has a well-established history of proven performance in the required application. This should be further backed by an acceptable longer term material weathering warranty from the geomembrane manufacturer.

Completing a site assessment and water analysis is an important part of the material selection process. This includes determining pH levels, disinfectant type and levels, other chemicals involved and water temperatures. Chemicals used for disinfectants in municipal water treatment include chlorine and chloramines and can function as accelerators in breaking down or leaching out the protective antioxidant packages of certain geomembranes resulting in environmental stress cracking and premature material failure (Mills 2011). Other related conditions include regions of high UV radiation, warmer ambient temperatures, cold temperatures and material folds and creases. These conditions have been known to further accelerate the degradation of certain geomembrane material as well as impact the floating cover performance.

In addition to flexibility, other important mechanical properties of the material should include tensile strength, elongation, tear, puncture, UV resistance and stress crack resistance. It is important that floating cover materials have the ability to retain key mechanical properties including tensile during the expected life of the floating cover. In potable water applications, the materials should have potable water certification including NSF 61 and meet other regional regulated requirements.

Additional independent material performance testing in more challenging or unknown project applications should be considered when choosing a geomembrane material. This can include accelerated chemical testing where material samples are immersed in higher temperature liquids and evaluated for various criteria including antioxidant retention levels, tensile strength losses and surface stress cracking. It is recommended that immersion testing be performed for periods of 60 – 180 days for best results. Further references for chemical immersion testing and related environmental stress crack testing include ASTM D5747, ASTM D1693 and the EPA Test Method 9090A.

The expected lifecycle of floating covers can vary by application and can range from 5 – 30 years. Based on the authors' experiences, **Table 3** below shows a suggested service life expectancy by material type for floating covers used for municipal water storage applications. Note, this is an approximation only by general material polymer type and can vary by specific manufacturers product formulations. Another important factor for achieving longer term performance of the floating cover material is having a proper operations and maintenance plan during the life of the floating cover.

Suggested Service Life for Floating Cover Materials in Potable Water Applications	
Under 10 Years	Lightweight RPE, LLDPE (GM 17), PVC
10 – 20 Years	RPP, EIA-PVC, TPO's, PE Alloys
20 – 30 Years	CSPE

Table 3. Projected service life of a floating cover by material type

FLOATING COVER FABRICATION

Based on the need for floating cover materials to move and flex with changing water levels, the materials used for floating covers requires very good flexibility and the ability to be prefabricated into custom size panels in the factory.
Geomembrane roll stock materials are typically prefabricated into custom-sized panels based on specific size and configuration based on reservoir geometry and location within the reservoir. There are many performance advantages of using factory fabricated panels for floating covers. The constant and favorable factory-controlled environmental conditions yield higher quality, including, better seams between individual geomembrane rolls, than field fabricated geomembranes and fewer opportunities for damage by field activities and personnel. The Fabricated Geomembrane Industries (Stark et al. (2020) has previously compared factory and field welded thermal geomembrane seams for a large off-stream water reservoir project. This comparison showed that factory welded seams exhibit higher seam peel and shear strengths, less variability, and more consistency than field welded thermal seams. The compiled test results showed that factory seams are about 10% stronger than field seams. Factory fabrication can typically result in about 75% less field seams on a project.

In addition to the prefabrication of the floating cover panels, several of the floating cover components and appurtenances can be prefabricated further saving installation time and costs. These include trough float caps, trough ballast tubes, sand tubes, access hatch floats, vent floats, walkways, and access steps.

Testing of factory fabricated seams should be performed in accordance with ASTM D751, D7747, D7982 (reinforced geomembranes), D882, D6214, D6392 (unreinforced geomembranes), or other relevant test methods. Trial welds should be performed prior to starting any panel fabrication. The trial welds must pass all seam peel and shear strength requirements before any panel production starts. Welders should be prequalified prior to commencement of welding and retested at 4-hour intervals. It is recommended that all seams, and patches, be 100% air-lance tested per ASTM D4437. The results of all testing must be documented and available to the owner and/or project engineer of record. All factory testing should be fully documented and stored as part of the fabricators FQA procedures for further reference and submittal purposes.

INSTALLATION PRACTICES

The installation of a floating cover is normally quite different than that of a standard geomembrane project. Floating covers by design require considerably more detailed installation work on the floating cover related to the various troughs, floats, ballast, hatches, vents, and other components not normally required on a standard geomembrane installation (see Figure 7). Floating covers also normally require the installation of highly flexible materials which are prefabricated into larger custom size panels. This can be particularly challenging for non-experienced installers resulting in installation cost overruns, potential quality problems, and sub-standard in-service performance.

Owners and engineers should establish a minimum amount of prior floating cover installation experience by material type as part of approving qualified floating cover fabricators and installers. An example of this would be requiring a minimum of 3 million ft^2 (278,709 m^2) of similar reinforced geomembrane material fabrication and installation experience within the past 5-year period.

DRY INSTALLATIONS

Figure 7. Crew installing floats and caps near Pittsburgh, PA.

Most floating covers are installed in dry conditions whether as a part of a new floating cover installation or replacement floating cover. Working with larger prefabricated factory panels, the installer will require the correct material handling equipment for transporting and placement of fabricated panels. All factory panels are required to be labelled in the factory and installed in the proper sequence and location as per the approved project installation drawings. All field welded seam strength properties should be performed in accordance with the Geosynthetic Institute GM 19 A for non-reinforced and GM 19 B for reinforced (GRI GM 19) or meet the manufacturers or engineers field seaming specifications. Another information source is the Fabricated Geomembrane Institute (FGI) website for typical installation details and a geomembrane guide listing various manufactured materials and specifications. The International Association of Geosynthetic Installers (IAGI) also provides installation guidelines for fabricated geomembranes on their website. The following is a list of industry resources for installation of geomembranes and floating covers.

- Fabricated Geomembrane Institute (FGI) – FabricatedGeomembrane.com
  - Typical Installation Details
  - Geomembrane Guide
- Geosynthetic Institute (GSI) – Geosynthetic-institute.org
  - GRI GM 19a & 19b Seam Strength and Related Properties of Thermally Bonded Homogeneous and Reinforced Polyolefin Geomembranes/Barrier
- International Association of Geosynthetic Installers (IAGI) – iagi.org
  - Geomembrane Installation Guidelines
- American Water Works Association (AWWA)
  - CA/NV Section, *Reservoir Floating Cover Guidelines*
  - Manual M25, *Flexible Membrane Covers and Liners for Potable Water Reservoirs*
  - Standard D130, *Geomembrane Materials for Potable Water Applications*

At the completion of the floating cover installation, the floating cover should undergo inflation testing prior to being put into operation. Inflation of floating covers includes inflating the floating cover using positive pressure. On larger floating covers, this often requires inflation testing by sections using inflation hatches and sand tubes for weights. When the floating cover is inflated, a technician will go under the floating cover with proper safety equipment to determine if they can see any light coming through the floating cover because of a tear, puncture, or welding problem. Any areas of concern are communicated with a technician above the floating cover who can then mark the point of concern for further investigation and repair.

WET INSTALLATIONS

When reservoirs cannot be taken out of service or the water fully removed, the floating cover needs to be floated in place on top of the reservoir surface while it remains in service (see Figure 8). This is referred to as a wet installation and can be more challenging as compared to a dry installation. The installation requires a sufficient available space located at one end of the reservoir for staging, deployment and field fabrication of the factory supplied floating cover panels. Factory fabricated panels are deployed outside the reservoir in the width direction and pulled into place using heavy gauge ropes and equipment located on each side of the reservoir. Typical equipment for pulling the panels into place include forklifts, backhoes, or trucks. The first panel requires a special reinforced leading edge with additional structural support and floats built into it to prevent it from tearing or sinking while being pulled into place.

On larger projects, multiple prefabricated geomembrane panels may be required so the factory fabricated panels can be welded together on site and then floated into place. Additional surface floats and float caps can be fabricated on site prior to the panel being pulled into place. As each single panel is pulled into place, the last panel edge remaining on top of the deployment area is then welded to the first edge of next unrolled panel. This process of welding additional panels is required until all panels are installed ensuring complete coverage of the pond surface area. Similar to a dry installation, field welding should be performed in accordance with GRI GM 19.

The floating cover panels need to be installed in good weather conditions, which includes low wind conditions. The project owner and installer must verify satisfactory weather conditions before scheduling the installation. Once all the floating cover panels are pulled into place the floating cover needs to be immediately secured whether in an earth anchor trench or mechanically attached to a concrete curb. Temporary anchorage is recommended while the floating cover is being permanently anchored.

For further information on installing floated in wet floating cover systems, reference the FGI Guideline for Biogas Cover Systems.

Figure 8. Floating Cover being pulled into place with rope and reinforced leading edge.

OPERATIONS & MAINTENANCE PLAN

A well-defined, site-specific service inspection and repair program helps ensure long-term effectiveness of lined reservoirs and floating covers. Floating covers are well known to demonstrate longer term service life from regularly conducted inspection and maintenance. Documented inspections enable operators to detect and address various signs of potential damage or leakage and make required repairs. Without a proper documented operation and maintenance program in place, floating covers will over time develop problems associated with material tears, punctures and leaks resulting in potential premature failure of the material and floating cover.

While operators should regularly monitor the surface of the floating covers for site anomalies. These can include ponding water on top of the floating cover which could indicate a leak or rainwater pump malfunction or required tensioning adjustments to the floating cover. It is recommended that floating covers undergo regular inspection and maintenance in accordance with a prescribed operations and maintenance plan. This can include a surface inspection of the floating cover, rainwater removal pump maintenance, floating cover cleanings, and underwater inspections performed by divers or remote operating vehicles (ROVs) with cameras. Any tears, holes or areas of concern need to be fully documented before and after repair. For further information on operations and maintenance, reference American Water Works Association publications or the Fabricated Geomembrane Institute (FGI) Operation and Maintenance Guideline for Geosynthetic Lined Water Reservoirs.

SAFETY

Proper safety practices are paramount on floating covers to avoid the risk of drowning or serious injuries from falls. Safety procedures should include properly designed walkways on the floating cover, ladders, and access ropes. Unexperienced personnel on top of the floating cover should avoid the trough and sump areas. A minimum of two experienced people with a communication system should be on site when working on or inspecting the floating cover. Other important safety equipment includes the mandatory use of lifejackets, proper footwear, ropes with attached floats, and a safety knife. Safety procedures and training programs are required for all personnel operating on or near the floating covers including operations staff and site visitors. A security fence should be installed around the perimeter of the reservoir to prevent unapproved access, vandalism, and potential accidents.

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