# Modular geosynthetics construction

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Modular construction is a process in which a building or other item is constructed primarily off-site; under controlled factory conditions; and using the same design, materials, equipment, testing and construction quality control and assurance (CQC/CQA) techniques as a field-constructed facility—but usually in about one-half the time (Modular Building Institute). Roof trusses, wood or concrete tilt-up walls, shower enclosures, tile patterns and other items are all examples of products that have adopted modular construction.

In modular construction, portions of the project are produced in "modules" that, when put together on-site, reflect the design, specifications, materials and quality of the most sophisticated field or on-site constructed facility (Modular Building Institute). In addition, the factory-controlled process generates higher quality, less waste, fewer site disturbances, and a more predictable and shorter construction schedule.

This article focuses on the use of modular construction for geosynthetics. The same benefits of using modular construction for buildings can be realized with geosynthetics. For example, installation of a factory-fabricated geomembrane can occur simultaneously with site work, allowing the project to be completed in as much as one-half of the time required for traditional field fabrication. Another example is factory-fabrication of geosynthetic tubes for coastal protection, cofferdams or a dam system to isolate parts of a river channel for sediment removal (Fraser and Neal 2021). More importantly, weather delays can be significantly reduced because 60%–100% of the fabrication can be completed inside a factory instead of the field, which mitigates the risk of weather delays. This results in the containment system being utilized sooner and creating a faster return on investment (Modular Building Institute). Removing approximately 60%–100% of the geomembrane fabrication from the site also significantly reduces site disruption, vehicular traffic and hydrocarbon-powered equipment, and improves overall site safety and security.

Factory-fabricated geosynthetics are constructed with the same materials, equipment and technicians, and to the same design standards, as field-fabricated geosynthetics. However, the constant and favorable factory-controlled environmental conditions yield higher quality—such as seams between individual geomembrane rolls—than field-fabricated seams. Stark et al. (2020) 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 at yield, less variability and more consistency than field-welded thermal seams. In particular, the results showed that factory seams are about 10% stronger than field seams in shear and about 9% stronger in peel

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strength at yield. More importantly, this resulted in 100% of the factory-welded seams passing the project seam strength requirements, even though the factory-welding speed was 1.1–1.6 times faster than the field-welding speed. Conversely, about 25% of the field-welded seams did not pass the initial specified field seam shear strength requirement, which caused significant delays, scheduling problems and other construction issues. To facilitate field acceptance, the field seam shear strength requirement was reduced from 7,081 pound-force per foot (9.6 kN/m) to 6,048 pound-force per foot (8.2 kN/m) to decrease the number of field seams failing project requirements (Stark et al. 2020). Because the geomembrane was primarily factory fabricated, there were about 78% fewer field seams on this project than if the geomembrane was entirely field fabricated, which allowed the project schedule to be achieved.

The constant and favorable factory-controlled environmental conditions also reduce the risk of accidents and related liabilities for workers (Modular Building Institute). Further, factory fabrication provides better construction quality management because a factory can implement stringent CQC/CQA programs with independent inspection and testing protocols that promote quality for 60%–100% of the required fabrication process.

As owners and designers look for more sustainable designs for improved environmental impact, they will find that modular construction is inherently more sustainable than field fabrication (Modular Building Institute). Fabricating in a controlled environment reduces waste by allowing complex panel geometries to be created from rectangular rolls and reusing the cut material without having to clean it or ship it back. This efficient waste reduction and reuse, along with improved quality management throughout the fabrication process and less on-site activity, promotes sustainability (Modular Building Institute).

For many decades, modular construction has been a part of the geomembrane industry in the form of factory-fabricated geomembranes. Modular construction involves seaming individual rolls of geomembrane in an off-site, controlled facility to create large panels or modules that are assembled at the project site. Advancements within the industry have allowed delivery of factory-fabricated and factory-certified geomembrane panels or modules to a jobsite, and those materials can be deployed to cover a large area in a short period of time (**Figure 1**). The deployment of large panels is contrasted

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**FIGURE 1** Deployment of a large factory-fabricated geomembrane panel

with the deployment of a single roll of geomembrane, and cutting, sizing and seaming these rolls in the field under variable and sometimes harsh conditions (**Figure 2**). The use of factory-fabricated geomembrane panels allows rapid deployment and installation of geomembrane panels ranging in size from 0.25 to 200 acres (0.1 to 80.9 ha). The fabricated panels greatly reduce installation time, labor and per diem costs; worker injuries; destructive testing and patching of the final geomembrane; and field quality control and assurance observations and testing. The geosynthetics industry has proven over the last 30 years that modular construction can yield excellent finished containment systems.

**FIGURE 2** Cleaning seam area for field fabrication and seaming of two field-deployed rolls of geomembrane

## Cost comparison

Because the cost of installation and third-party CQA of a geomembrane for a containment system can be comparable to the cost of the geomembrane itself, field installation and CQA must be optimized/minimized to obtain the most benefit for the owner and not slow overall construction. The Fabricated Geomembrane Institute (FGI) created a cost comparison calculator/spreadsheet that can be used to estimate the installation and CQA cost difference between factory- and field-fabricated geomembranes in addition to the quality benefits of factory-fabricated geomembranes highlighted by Stark et al. (2020). The cost comparison calculator/spreadsheet can be downloaded free at https://www.fabricatedgeomembrane.com/protected/pond-liner-calculator. The cost comparison does not include the cost of the geomembrane or other required materials. This calculator is "For estimating purposes only," and a formal cost estimate should be conducted for each project. The calculator can be used for other geosynthetics, such as factory-fabricated geotextiles.

The cost comparison between factory- and field-fabricated geomembranes includes factors such as the shorter on-site time; less field seaming, sampling and testing; reduced installation crew expenses, such as per diem and lodging; and quicker installation using factory-fabricated geomembranes. The cost comparison for a 2.3-acre (0.9-ha) pond is presented below to illustrate the reduced costs with a factory-fabricated geomembrane, which also results in a higher-quality installation because most of the seams are completed in a climate-controlled and clean factory setting (Stark et al. 2020). For the hypothetical 23-acre (9.3-ha) pond used herein, the installation and CQA cost of a factory-fabricated geomembrane is 65% less than for a field-fabricated geomembrane, i.e., $33,513 versus $97,034.

## Complex geometries

Another major advantage of factory fabrication is the ability to prefabricate complex geometries or irregular cells, varying slopes and slope breaks rather than trying to cut and size all the pieces in the field with changing and challenging weather conditions. For example, **Figure 3** shows the prefabricated panel layout diagram for a large hydroelectric dam and reservoir that requires many irregularly shaped panels, especially in the corners. The panel layout diagram shows 80 different panels that were factory fabricated and seamed in the field to line this 800,000-square-foot (74,322-$m^2$) hydroelectric water storage dam and reservoir. The geomembrane used for the project is a 36-mil (0.91-mm) thick

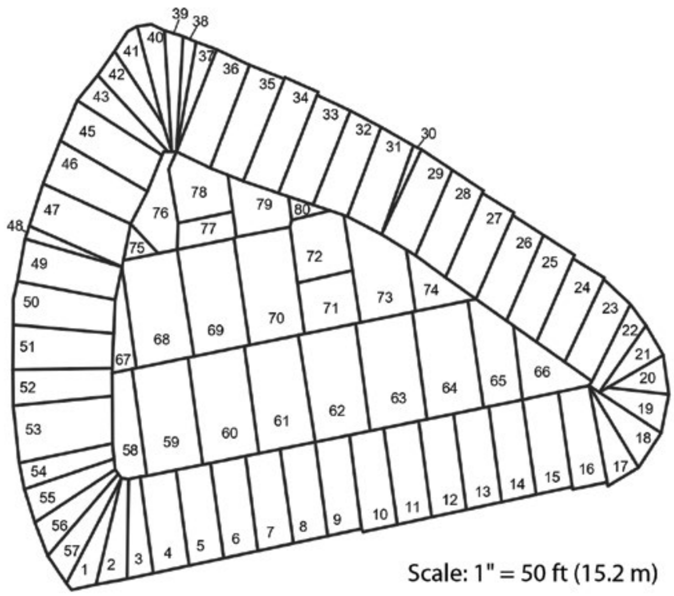


**FIGURE 3** Panel layout diagram showing 48 different panels for factory fabrication

**FIGURE 4** Irregular-shaped geomembrane panels for a shale oil and gas development project

Hypalon geomembrane. Another example is shown in **Figure 4** and consists of factory-fabricated geomembranes of various sizes and shapes for secondary containment at a shale oil and gas development project. In addition to complex panel geometries, factory fabrication allows prefabrication of time-consuming geomembrane accessories, such as pipe boots, ballast tubes, vents and other custom appurtenances, which greatly reduce field time and increase the quality of the welding through the use of controlled factory conditions and different types of welding equipment for large and small pieces (e.g., geomembrane accessories and seaming). For example, dielectric welding or seaming is efficient and produces high-quality welds in the factory, but it cannot be used in the field due to its size and power requirements. In the factory, fabricators can also build custom jigs and ways to weld and produce geomembrane panels and accessories more efficiently than in the field, which can significantly reduce costs to the owner.

Irregular geometries are particularly suited to factory-fabricated panels because individual rolls of geomembrane require longer field time, which is complicated by day-to-day temperature fluctuations that result in significant differential expansion/contraction. For example, **Figure 5** shows a small municipal solid waste landfill cell that was lined with individual geomembrane rolls during the summer of 2020. Because the installation required several days, worrisome wrinkles developed. As a result, the geomembrane installer had to return to the site one month later to cut out some of the large wrinkles that had aggregated even after the geosynthetic drainage composite was installed above it.

**FIGURE 5** Large wrinkles developed in a landfill expansion with irregular slopes—due to thermal expansion—after the HDPE roll goods were deployed and covered with a geocomposite drainage layer.

## Geomembranes used in modular construction

Geomembranes that can be used in modular construction are flexible but still chemical resistant because they are rolled or folded in the factory after they are cut and seamed for shipping to the site. However, this flexibility provides many other advantages for the installation and long-term performance of the geomembrane, including increased ability to conform to subgrade changes; increased deformability to subgrade protrusions, bumps and rocks; decreased number and size of wrinkles because of greater subgrade contact and lower bending modulus; lower coefficient of thermal expansion; and less leakage because of greater intimate contact with the underlying subgrade or compacted soil. If desired, flexible geomembranes also can be reinforced with a geotextile scrim fabric to increase dimensional stability and increase intimate contact with the subgrade to decrease wrinkles and leakage, increase puncture resistance, and maintain long-term dimensional and slope stability.

To facilitate modular construction, folding of the panels is important because large panels need many people to unfold them across a site. Normally, each person can pull out about 100 pounds (45 kg) of geomembrane, an estimate that can be used to calculate how many people are needed to pull out a geomembrane panel. To reduce the number of people and auxiliary forces, the geomembrane panel can be rolled up on a steel core or pipe. If the outer sides of the sheets are folded to the center and then the panel is rolled up on the steel core, the laborers in the field only have to pull out half of the panel weight when they unroll the panel from the middle of its final position instead of one edge. This also accelerates deployment and covering of the subgrade, geosynthetic clay liner (GCL) or compacted soil liner before adverse weather arrives.

## Summary

To look at the origin of modular construction, you can go back to the 1670s; however, the real boom in America occurred after the Second World War when it was utilized to provide fast, low-cost housing for workers and returning servicemen. Since then, modular construction has been used primarily in residential housing and low-rise buildings. In recent years, this concept makes more and more sense as we see multiple ways prefabricated panels can enhance quality and reduce wasted resources. Modular construction and factory fabrication of geosynthetics also yields a smaller carbon footprint because electrical power generated from renewable sources or less carbon-intensive sources can be used for 60%–100% of the geomembrane and geotextile seaming instead of the hydrocarbon energy sources used for field fabrication. In summary, modular construction/factory fabrication results in high-quality, sustainable, innovative, efficient, cost-effective and faster geosynthetic installations (**Figure 6**).

**FIGURE 6** Aerial photo of containment areas with irregular geometry

### References


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