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# GFRP Wicket Gates: Long Lasting Structures to Ensure Navigable Waterways

## Composite Advantage, LLC

*Government engineers teamed with academia and an innovative manufacturer to produce a novel composite materials product proven as a successful replacement for standard chanoine-type wicket gates made of white oak. Innovation was required in three areas: (1) development of glass fiber reinforced polymer (GFRP) composite material configuration, (2) development of a new gate manufacturing process, and (3) optimization of structural design. This innovation is the first navigational structure made of composite materials to be used by the U.S. Army Corps of Engineers (USACE), which maintains navigation on the nation's valuable waterways. Wicket gates create an adjustable dam by controlling pool levels and allowing river traffic to flow without locking through the lock chamber. The new product works the same way, but exceeds existing gate performance in cost, durability, maintenance, and safety.The innovative GFRP composite wicket gate costs 40% less on a first-cost basis, provides an environmentally conscious alternative to old-growth hardwood, and increases a gate's lifespan from 15 years to 50 years. A longer lifespan saves repeated installation costs, increases diver safety by avoidance, and projects virtually no maintenance costs. The product has been proven successful through research, design, testing, and validation in actual river use. A 2018 budget request was submitted by USACE's Rock Island District to replace all existing timber wickets with composite wickets at two Illinois River sites. At those two sites alone, replacement with GFRP wicket gates will save $18.6 million in materials and labor over 50 years, providing a return on investment of 28.6:1 on development expenditures of $650,000. This product's innovation paves the way for the use of GFRP composites nationwide by USACE and other governmental agencies on a multitude of additional navigation and water-control structures with even more demanding performance requirements, such as large culvert valves and radial gates.*

**CONCEPT & DESIGN** The nominated product represents the first-ever use of GFRP material in manufacturing a large navigational waterway component in the United States. The nation's navigable waterways are especially important to successful, uninterrupted, and cost-effective commercial transport and recreational use. Many waterways contain locks and dams to maintain water levels necessary to allow vessel passage. The wicket gate component is raised to form a dam in low water conditions. Current timber wicket gates are made of solid white oak, an expensive and diminishing natural resource. High costs and lack of resource availability drove the new wicket gate's concept and design, as government agencies continue to look for ways to meet ongoing budget constraints. Also inherent in the manufacturing decision is continuing successful GRFP product development for Army infrastructure. Researchers at the Army's Engineer Research Development Center-Construction Engineering Research Laboratory (ERDC-CERL) have successfully co-developed and implemented other GFRP products such as bridge decks and railroad ties. This expertise led to considering composites as an innovative replacement material for navigation structures such as wicket gates. Sustainability is inherent because the new product uses material that is not a limited source and has a long life expectancy. The new product works the same as existing timber wickets, but exceeds their performance in cost, manufacture, lifecycle, environment, maintenance, and safety factors. The design and manufacturing flexibility of composites enabled a structurally superior part to be manufactured to the same form and function as the traditional wood product. A repeating pattern of internal structure allows for manufacturing efficiencies and a lighter weight aids shipping. The composite product uses existing attachment hardware, support foundations, and installation equipment to eliminate additional implementation costs or field installation challenges. Design challenges included meeting minimum stiffness requirements while matching overall weight, balance, and buoyancy metrics of an existing timber wicket gate.

**VALUE** The innovative new wicket gate represents a significant advancement in using GFRP composite materials for navigation structures. This less costly and more durable product is needed to replace traditional white oak wicket gates that average 15 years in service. There are over 200 wicket gates at two dams along the Illinois River alone. Material costs plus labor costs are significant for maintenance and frequent replacement of existing wicket gates. Compared to the existing product, the nominated product is more saleable because it provides multiple benefits: (1) it performs equally or better under use, (2) it increases long-term durability and lifespan more than three-fold, (3) it avoids using scarce and costly timber resources, (4) it can be manufactured for approximately 40% less on a first-cost basis, (5) its yellow color increases visibility and safety, and (6) its greater life expectancy increases diver safety by reducing frequency of replacement and repair. Most importantly, all inland navigation will benefit from follow-on manufacturing of GFRP navigation structures, now that a large component has been validated. GFRP is the optimal material to replace old-growth hardwoods. For manufactured GFRP, there is no limit on material availability, so its material costs are more stable. GFRP material properties are designed and manufactured to be superior to wood—strength is two times better, and the GFRP properties do not degrade over time and exposure. Manufacturing of engineered, prefabricated products produces consistent structural properties, unlike the variability of wood products. Manufacturing costs are minimized by creating an integral, unitized part with unique shapes,

reducing assembly time and costs to enable the GFRP gate to be lower first cost, which is the exception for most composite parts. Purchasers have confidence since all the product's benefits have been proven by engineering, testing, manufacturing, monitoring, and inspection.

**IMPACT** The nominated product can have a multimillion-dollar impact on operational costs of waterways. USACE elements currently operate more than 200 navigational locks and dams. In 2014, 566 million tons of commodities were transported on these waterways. Failure of any dam component can have a million-plus dollar-per-day impact on riverway commerce due to time delays, extra mileage traveled for detour or avoidance, and potential cargo damage.By engineering the GRFP component to work exactly as the existing wood component, the product contributes to user acceptance of GRFP materials. The product's now-proven and first-ever use in USACE waterways adds to the navigation construction market's confidence in using GRFP composites. For instance, new designs with this GFRP material are planned to manufacture similarly cost-effective and durable replacement structures for lock culvert valves and radial gates. The product's success in a new construction environment adds to the emerging market for using GRFP composites. Given the economic and safety impacts of waterways, it was important for any new technology to prove itself. The now-proven composite wicket gate also opens the opportunity to apply this technology to more waterways, including international markets.The innovation addresses society's environmental, financial, and commercial needs with a longer lifecycle, less disruption for maintenance, and highly fuel-efficient transport of goods via waterways. It also is manufactured using a resource with a lower carbon footprint than old-growth wood. The innovation's use also enhances society's safety in commercial transport, national security, and public recreation. The innovative product will successfully replace older products that have less durability, higher expense, shorter lifespans, and negative environmental impacts. Thus, the product significantly advances the scope of using composites for future development of other large infrastructure in all markets, while currently offering a cost-effective and more durable product to the navigation construction industry.

**PRODUCTION & DELIVERY** With no engineering design available, an existing timber gate had to first be reverse engineered. Capacities and service loads were calculated for various cases. The replacement gate was required to utilize existing gate hardware; have the same weight, buoyancy, and center of gravity; and have equal or greater bending and shear capacity.Design optimization went through several iterations. A commercially available manufacturing technique, Vacuum Infusion Process, was chosen to produce a high-quality monolithic component. This process combines fiberglass fabric with core materials inside a mold and then uses a vacuum to pull thermosetting polymer resin through it. The manufacturing process includes multidirectional fiberglass fabric, a foam core wrapped in the fiberglass fabric and then, vacuum bagging of the fiber and foam package for polymer resin transfer.A prototype was manufactured for testing and evaluation. Mechanical property tests were completed on the prototype and coupon-level specimens. Loading levels were within 40% of the ultimate load, and failure loads were considered for different support conditions. Bending and shear strains were measured on the upstream and downstream sides, center, and hinge and prop locations. Based on testing, the prototype GFRP gate resisted an applied bending moment of 300 kip-ft, with the maximum design bending moment for the GFRP wicket gates being 122 kip-ft. The predicted bending moment at failure is 488 kip-ft, resulting in a factor of safety of four. Yellow UHMWPE (ultra-high-molecular-weight polyethylene) was incorporated on the face and sides of the gate for abrasion resistance and visibility (safety).The wicket gate is ready for commercialization. The manufacturing process is well established, and materials are commercially available. The commercialized product will be the same construction as the proven prototypes. The product is manufactured using a repeatable process that can be implemented in multiple manufacturing cells to meet required quantities.

**COLLABORATION** Researchers at ERDC-CERL tapped into existing research relationships with composite materials experts at West Virginia University to design parameters and full-scale testing. The team also partnered with practicing engineers at other USACE elements including three Districts and the Inland Navigation Design Center to develop design and performance criteria, design risk assessments, and select sites available for installing and monitoring validation tests of the product. Including the USACE Rock Island District as the end user/owner ensured that personnel had inputs in the requirements and objectives, producing higher interest in implementing the product.For actual production, the ERDC-CERL team partnered with privately owned Composite Advantage of Dayton, Ohio, for its expertise in design and fabrication techniques for monolithic component construction. This manufacturing partner was selected for its molding processes and fiber reinforced polymer recipes that make it one of the few advanced material manufacturers able to fabricate very large, highly loaded structures.Collaboration between all of these entities produced an effective partnership consisting of government (end user and technology sponsors), academia, and industry representatives. Having all organizations discussing design and implementation at the same time allows the end user to influence the details of the product, Other collaborators thereby learn the underlying reasons for end user requirements.The nominated product will be highly competitive in the marketplace with a proven ROI of 28.6:1. As an early example of confidence in the manufacturing, performance, and cost savings of the product, a total of 219 GFRP wicket gates were requested in the 2018 budgets of the LaGrange and Peoria Lock & Dam locations on the Illinois Waterway, managed by the Rock Island District Corps of Engineers. The purchase is estimated to result in $18.6 million in savings for materials and labor over the product's expected 50-year lifespan.

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