Fiber Reinforced Polymer (FRP) Composite Bulkhead Slot Filler Panel

Response Summary:

The Little Rock District of the US Army Corps of Engineers (CESWL) submitted a Dredging Operations Technical Support (DOTS) request for technical assistance in studying the feasibility of a bulkhead slot protection plate, also known as a filler panel, made from glass fiber reinforced polymer composites. ERDC researchers traveled for a site visit, assembled historical information, and conducted market research to determine the rough order of magnitude weight and cost for a feasible protection plate concept made from pultruded composite materials. The concept weighs approximately 4,300-lbs. and carries material costs of about $50,000.

Panels are included in the analysis found in the ERDC Special Report (ERDC SR-24-3, http://dx.doi.org/10.21079/11681/48755), “Composite Material Applications and Research Roadmap for US Army Corps of Engineers Civil Works,” though at low priority with a Normalized Combined Component Score in Table B-4 of only 0.67 out of 10. The subjective assessment on page 83 of the Research Roadmap does recommend consideration of composite materials for this application.

Period of Performance:

30 November 2023 to 06 September 2024

Benefits of the Response to the USACE Dredging/Navigation Program:

The Navigation program benefits from extended engagement and communication of composite material prototypes and conceptual designs in support of Engineering and Construction Bulletin 2024-08 (https://www.wbdg.org/FFC/ARMYCOE/COEECB/ecb_2024_8.pdf), “Design of Fiber Reinforced Polymer Hydraulic Composite Structures.” Composite structures bring the potential to avoid hundreds of millions of dollars of lifecycle maintenance costs across the enterprise when compared with in-kind steel replacements of failing components. Additional details are available in the Composite Material Research Roadmap.

Deliverable:

The ERDC compiled a Letter Report in order to disseminate existing specific information and expand applicability of the solution across the enterprise.

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DOTS ID: DOTS-24-R131

ERDC/CERL LETTER REPORT

Construction Engineering Research Laboratory

US Army Corps of Engineers®
Engineer Research and Development Center

Dredging Operations Technical Support

Fiber Reinforced Polymer Composite Bulkhead Slot Protection Plate

Peter B. Stynoski, Molla H. Hasan, and Harrison A. Biggs

September 2024

Executive Summary

The Little Rock District of the United States Army Corps of Engineers (CESWL) submitted a Dredging Operations Technical Support (DOTS) request for technical assistance in studying the feasibility of a bulkhead slot protection plate, also known as a filler panel, made from glass fiber reinforced polymer composites. ERDC researchers conducted a site visit, assembled historical information, and conducted market research to determine the rough order of magnitude weight and cost for a feasible protection plate concept made from pultruded composite materials. The concept weighs approximately 4,300-lbs. and carries material costs of about $50,000.

1 Introduction

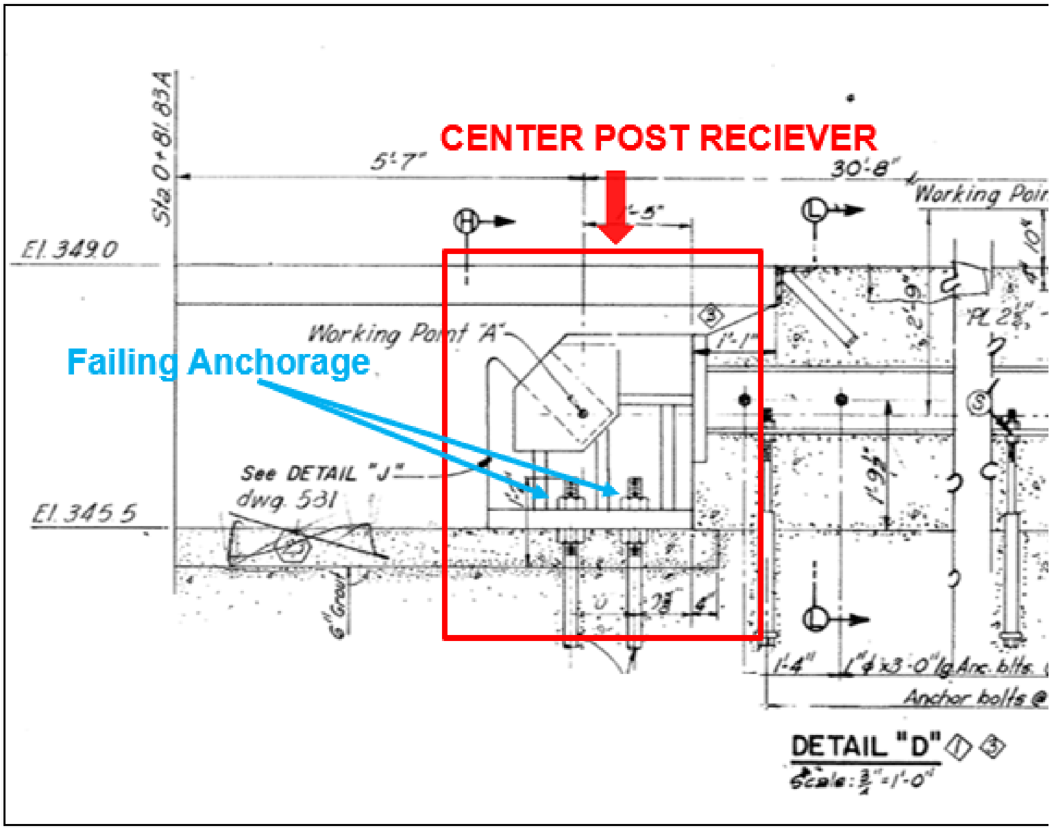
This report responds to a Dredging Operations Technical Support (DOTS) request for technical assistance in studying the feasibility of a bulkhead slot protection plate, also known as a filler panel, made from glass fiber reinforced polymer composites. The Little Rock District of the United States Army Corps of Engineers (CESWL) submitted the request.

1.1 Background

The McClellan-Kerr Arkansas River Navigation System (MKARNS) includes 18 lock and dam structures designed for vessels and barge trains no wider than 110-ft. The original structural designs call for dual 55-ft. bulkhead components (Figure 1) when conducting maintenance activities on the lock structures. The dual bulkhead design necessitates a center post anchored to the sill. Over time, the center post receiver anchorage has failed at several project sites (Figure 2).

Figure 1. Example of 55-ft. bulkhead and center post system in service.

Figure 2. Annotated drawing depicting center post anchorage in the sill.



After painstakingly considering options to address the failing center post anchorage, the decision was made to build monolithic, 110-ft. wide bulkheads. This course of action requires recess modifications to support additional loads and accept wider bearing surfaces. Such wider, deeper bulkhead slots also have greater propensity for barge allision in a situation colloquially referred to as, “hang-up.” Filler panels prevent such hang-up at many projects across the USACE enterprise. However, the tall height of the downstream slots on most MKARNS locks leads to heavy, cumbersome filler panels that are subject to frequent degradation cycles of frictional wear and corrosion.

1.2 Objective

We aim to conceive a feasible design of Fiber Reinforced Polymer (FRP) composite filler panels to fit the existing 110-ft. slot design while addressing several stressors, including corrosion (Figure 3), lift equipment limitations, and frictional wear. As stated by David Lovett of the Inland Navigation Design Center, “The district design staff is concerned that the size and weight of this [steel] assembly may create O&M costs in the future and that maintenance staff may opt to just scrap the plate assembly after it is removed for the first dewatering."

Figure 3. Corrosion on 55-ft. bulkheads in storage on the bank of the Arkansas River.

1.3 Approach

Our approach began with conducting a site visit to gain complete understanding of the geometric limitations of the slots. We also took numerous opportunities to interview maintenance and engineering staff, both virtually and onsite. Finally, we collected our site visit findings, references, and preliminary design concepts in this report.

1.4 Scope

The original DOTS request stated goals to deliver a complete design and perhaps manufacture a prototype. Unfortunately, the required load analysis, Engineer Manual compliance checks, and Professional Engineer signatory are well beyond the scope of a DOTS request. The ERDC and CESWL agreed to limit the deliverable to a report of existing knowledge and a preliminary design concept equivalent to approximately 10% Design Stage. Contracting for final design would range in the mid-5 figures. Contracting for prototype manufacturing would range in the high-5 to low-6 figures.

2 Site Visit and Existing Prototypes

Our site visit began at Norrell Lock and Dam (Lock 1), proceeded to the storage yard west of Lock 2, and concluded at the Emmett Sanders Lock and Dam (Lock 4). This route allowed us to prioritize our time at a site with 110-ft. modifications complete, while also viewing the 55-ft. and 110-ft. bulkheads in storage and 55-ft. slots at Lock 4. The slots at Lock 4 (Figure 4) exhibited extensive evidence of frictional wear on the armoring corner caps of the slots, but only limited evidence of hang-up impact damage to the corner caps.

Figure 4. Existing 55-ft. bulkhead slot on the upstream, river side monolith at Emmett Sanders Lock and Dam (Lock 4).

The 110-ft. bulkhead slot armoring panels at Lock 1 (Figure 5) are wider and more complex. The protection plates and armoring corner caps again exhibited extensive evidence of frictional wear from barge traffic concentrated at the lower section of the plate (Figure 6). Lock operations staff expressed confusion about the purpose of the protection plates, as barge trains are usually too long and wide to develop enough angle of incidence that would generate a condition of hang-up in the slot.

Figure 5. Installation of 110-ft. slot armor prior to concrete pour.

Figure 6. Frictional wear primarily on the lower portion of a bulkhead slot protection plate at Norrell Lock and Dam (Lock 1).

Prototype composite protection plates were designed, tested, and demonstrated for the Willow Island Lock bulkhead and valve recesses during 2015 and 2016. Researchers from the ERDC considered both molded components constructed by vacuum-assisted resin transfer molding (VARTM) as well as components assembled from parts made by pultrusion techniques. Four design concepts are described in a presentation that was delivered at the Transportation Research Board Committee on the Marine Transportation System 2016 conference in coordination with our academic partner (https://onlinepubs.trb.org/onlinepubs/conferences/2016/CMTS/Presentations/38.PVVijay.pdf). USACE published a Fact Sheet with similar information, "Fiber Reinforced Polymer (FRP) Composite Recess Filler Panels," available on page 26 of the 2016 Technologies to Extend the Life of Existing Infrastructure report (https://operations.erdc.dren.mil/pdfs/TechExtLife1.pdf).

For additional details about the prototyping and assessment activities, readers may refer to Section 3 of an upcoming Technical Report, "Monitoring and Assessment of Polymer Composite Materials Demonstrations in Civil Works Infrastructure Applications." As of September 2024, this Technical Report is in the final stages of publication; pre-publication excerpts are available upon request.

Readers may also take interest in the frictional wear characteristics of composites in this application. This topic is the subject of an active Navigation Systems Research and Development project in support of Statement of Need 2022-1767, "Utilization of Fiber Reinforced Polymers (FRP) on Navigational Dams." Draft performance-based specification language for wear-resistant composites is available upon request. Such specification must be coordinated with the Inland Navigation Design Center (INDC) in accordance with Engineering and Construction Bulletin 2024-08, "Design of Fiber Reinforced Polymer Hydraulic Composite Structures."

3 Loads and Design Constraints

The authors strongly recommend that the reader refers to the INDC Design Documentation Report (DDR) H4OR13202001 which discusses new bulkhead recesses and protection plates at the Dashields Lock and New Cumberland Lock. The Dashields design supports impact bearing loads against the concrete monolith and carries protection plate installation alignment loads through angle iron locators (Figure 7), just as in the existing design for MKARNS 110-ft. slots and protection plates. The MKARNS designs add non-load-bearing bumper blocks made from High-Density Polyethylene (HDPE) for additional alignment guidance during installation (Figure 8). Geometry details for the MKARNS design are included in this report for convenience of the reader (Figure 9 and Figure 10).

The New Cumberland DDR discusses the situation concerning standardized design impact loads. Phrasing from the DDR is copied below. Please refer to the latest INDC guidance for interim design loads.

> ETL 1110-2-563 has been rescinded, however, there is no current guidance for impact loads to lock walls. Since previous protection plates have been designed using this guidance, and have performed satisfactory, and there is no current guidance, the INDC recommends using the specified loading within rescinded ETL 1110-2-563 as a basis for this design.

A recent message from David Lovett of the INDC to a prospective initial design contractor boiled down the guidance to simplified metrics, which included the approximate weight of MKARNS 110-ft. steel protection plates.

> For a 30-ft. tall protection plate assembly, this equates to a weight of 12.5 kips. The protection plate assembly is designed for a barge load of 100 kips.

Figure 7. Depth locating angle iron on existing protection plate.

Figure 8. Existing protection plate installed at Norrell Lock and Dam (Lock 1).

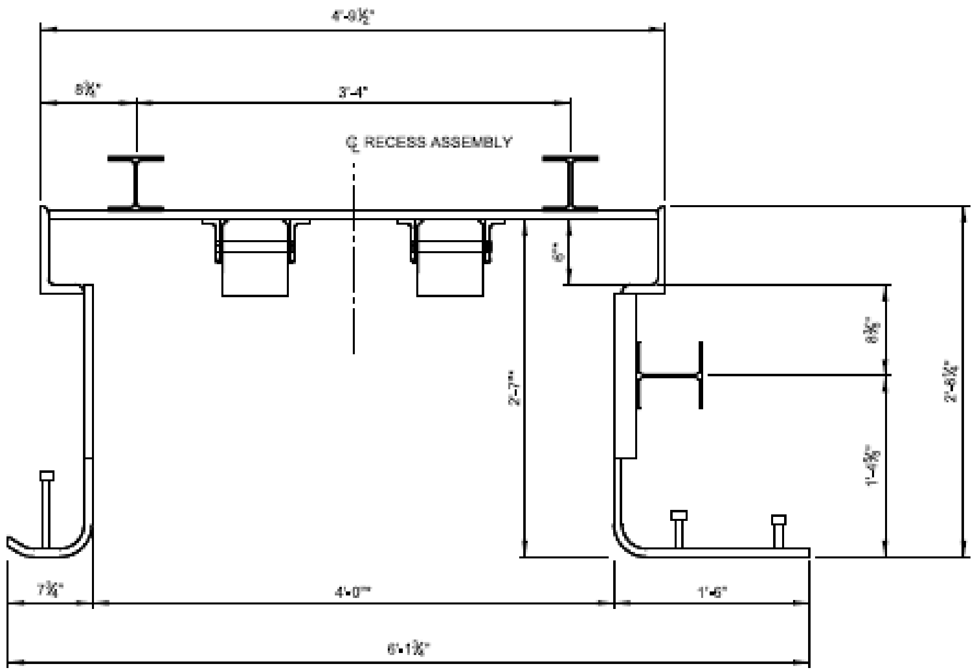


Figure 9. Geometry of 110-ft. bulkhead recess.

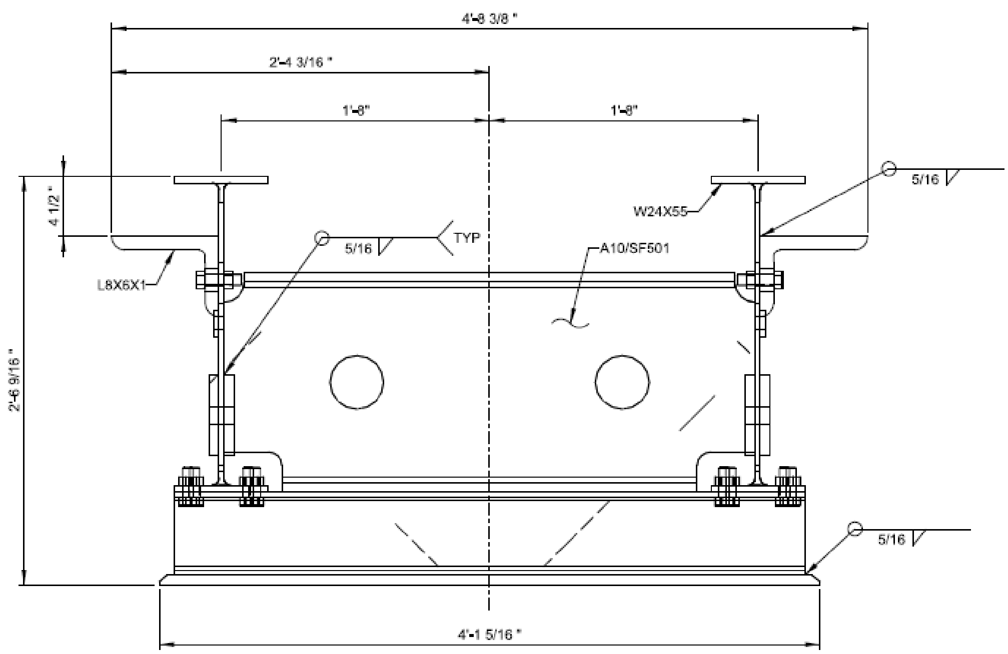


Figure 10. Geometry of protection plate.

4 Feasible Concept

Filler panels are included in the analysis of ERDC SR-24-3, “Composite Material Applications and Research Roadmap for US Army Corps of Engineers Civil Works,” though at low priority with a Normalized Combined Component Score of only 0.67 out of 10. The subjective assessment on page 83 of the Research Roadmap does recommend consideration of composite materials for this application.

Designers of composite structures must first consider the manufacturing method. A molded part would maximize performance through customization of geometries and load paths but could result in longer lead times and increased design costs. A pultruded part would maximize design simplicity and convenience but may result in significantly higher material costs. Both designs will be limited by the bearing capacity of the composite materials. Stainless steel bushing inserts may be required for the lifting eye pickups and turnbuckle connections. It is imperative that the designer coordinates fabrication method with the INDC early in the design process. A pultruded concept is considered here due to the resource limitations of the DOTS program.

The total weight estimate for a pultruded protection plate assembly, including bolts or adhesives, is approximately 4,300-lbs., which compares favorably with the 12,500-lbs. weight of the steel protection plate communicated in Section 3 of this report. The total material cost estimate for a pultruded plate comes to approximately $50,000, which includes $24,000 for the main structure, $18,000 for the bearing beams, $300 for the locating angles, and $7,700 for bushings, adhesives, bolts, and contingency. Details of the major elements follow.

This feasible pultruded design considers 30-ft. high worth of CP045 and CP046 SuperDeck elements stacked on their sides. From Section 3 of this report, we have a concentrated bending load of 100 kips. The SuperDeck spec sheet lists a maximum service load of 48 kips over a 78-in. span of CP045 and CP046 elements. The supporting I-beams provide a longitudinal span of only 40-in. (Figure 10). This span is not listed in the spec sheet, so design point loads will need to be verified with the manufacturer. At 15.5-in. per stack, the design needs approximately quantity 24 each of

CP045 and CP046 at 4-ft. lengths to run the 30-ft. height, for a total length of 96-ft. each. At 23 pounds per square foot, the weight estimate comes to 2,960-lbs.

Market research with one manufacturer indicated economic limitations with this pultruded concept. They offered a material estimate of $24,000 for a 30x4-ft.[2] plate, not including the locating angle sections and bearing I-beams. Economies of scale could apply across approximately 20 project sites on the MKARNS and Upper Ohio River navigation system.

> We may need to consider a molded option, as the pultruded option, if minimum quantities are met will be in the $200 dollars per square foot range.

The existing design bolts a 24-in. wide flange beam to the skin plate support structure to carry loads to the monolith. A SuperDeck design using 8-in. wide CP045 and CP046 elements would leave approximately 22.5-in. for load bearing I-beams, meaning a 24-in. section would not fit, and an 18-in. section would need blocking or stacking of multiple beams. Please note that a molded protection plate design would not suffer such geometric conflicts.

One manufacturer lists pricing for 12-in. flame resistant and ultraviolet inhibited beams at $3,800 for a 20-ft. length. Quantity 3 of these elements would be required for a 30-ft. tall protection plate. We must add costs for the larger required section and special-order premiums for 18-in. or 24-in. beams. The total weight of these elements would be about 1,100-lbs. based on published manufacturer data.

Pultruded angle locating elements are available from GSA Global Supply schedules in 6-in. sections at 5-ft. lengths for approximately $230 (FMRB3198486 https://www.gsaadvantage.gov/advantage/ws/catalog/product_detail?gsin=11000090902095). A feasible design would require quantity 2 of these elements (each cut in half) weighing a total of approximately 30-lbs.