Appendix B
Examples of FRP Composite Applications

B-1. Introduction

Paragraph 1-4 of the main text outlined categories of various immediate, short- and long-term applications of FRP composites. This appendix is included to present some of the Corps of Engineers' experiences with FRP's.

B-2. Gravity Drainage Structure

a. The Harrisonville and Ivy Landing Drainage and Levee District gravity drainage structure is located in southern Illinois along the Mississippi River and is inspected by engineers from the St. Louis District. During the 1985 annual inspection, deformation to the gravity drain pipes was noted and an associated settlement was occurring at the crest of the levee.

b. Two plans were considered for rehabilitation of the gravity drainage structure. One plan specified reinforced concrete pipe and the other plan called for fiberglass pipe. Both plans had approximately the same final cost, but due to the fact that the fiberglass pipe could be placed in lengths twice as long as the reinforced concrete pipes, reducing the number of joints, a decision was made to use the fiberglass pipe. Installation of the pipe is shown in Figure B-1.

c. The specification for the fiberglass pipe was based on a performance specification. The service conditions for the fiberglass pipe required that the joints be able to withstand 137.9 kPa (20 psi) of external hydrostatic pressure and not allow any infiltration or exfiltration of soil fines through the joint. Levels of compaction were specified and agreed to by the manufacturer, since the bedding material for the pipe was not a material generally recommended for use by the pipe manufacturer.

d. The installation of the pipes appeared to be progressing well until testing of the joints began. Approximately 25 percent of the joints failed the specified internal pressure test, and some of the joints contained noticeable offsets. Subsequent to discovering the deficient joints, the pipe manufacturer submitted data requiring very tight tolerances with respect to the joint installation. The pipe manufacturer also concluded that joint difficulties resulted because of nonuniform compaction of the bedding material, but the manufacturer's definition of uniform compaction exceeded standard industry tolerances.

e. Joint repairs were made to all joints due to the large number which failed the test. The repair consisted of overlaying the joints with resin-coated fiberglass strips (Figure B-2).

f. The repairs to the joints were successful and, in general, use of fiberglass pipe in the application is favorable due to its light weight. Fiberglass also has excellent flow characteristics. With respect to the problems encountered on the Harrisonville and Ivy Drainage District project though, a careful examination should be made of what type of bedding material is to be used prior to the selection of fiberglass pipe. The tolerances in compaction for a given material may be the governing factor as to whether the fiberglass pipe can be used in that application.

g. It should also be noted that, on this project, standard FRP composite handrail, grating, and ladders were used (Figure B-3). FRP materials were selected to reduce maintenance costs to the levee district. Further details of this project are reported in a paper from the 1991 Corps of Engineers Structural Engineering Conference, "Quadruple 84-inch Corrugated Metal Pipe Repair," (Atchley 1992).

B-3. Wicket Gate

a. Hydraulically operated wicket gates were being designed for use on the dam portion of the Olmsted Locks and Dam project on the Ohio River. Because utilizing hydraulics to raise and lower the wicket gates of this size has not been used before and since hydraulically operated wicket gates have never been used in the United States, a decision was made to build a set of prototype wicket gates near Smithland Locks and Dam (also on the Ohio River) to ensure proper operation and to determine required maintenance procedures. A decision was made to include a gate constructed of FRP materials to determine the performance of these materials in a river environment.

b. Seven prototype wicket gates were constructed and, of these seven, one was constructed using FRP materials (composite wicket gate). The other gates were constructed using steel and were designed by the Louisville District. The specification for the composite wicket gate was a performance specification which limited the

Figure B-1. Installation of FRP pipe

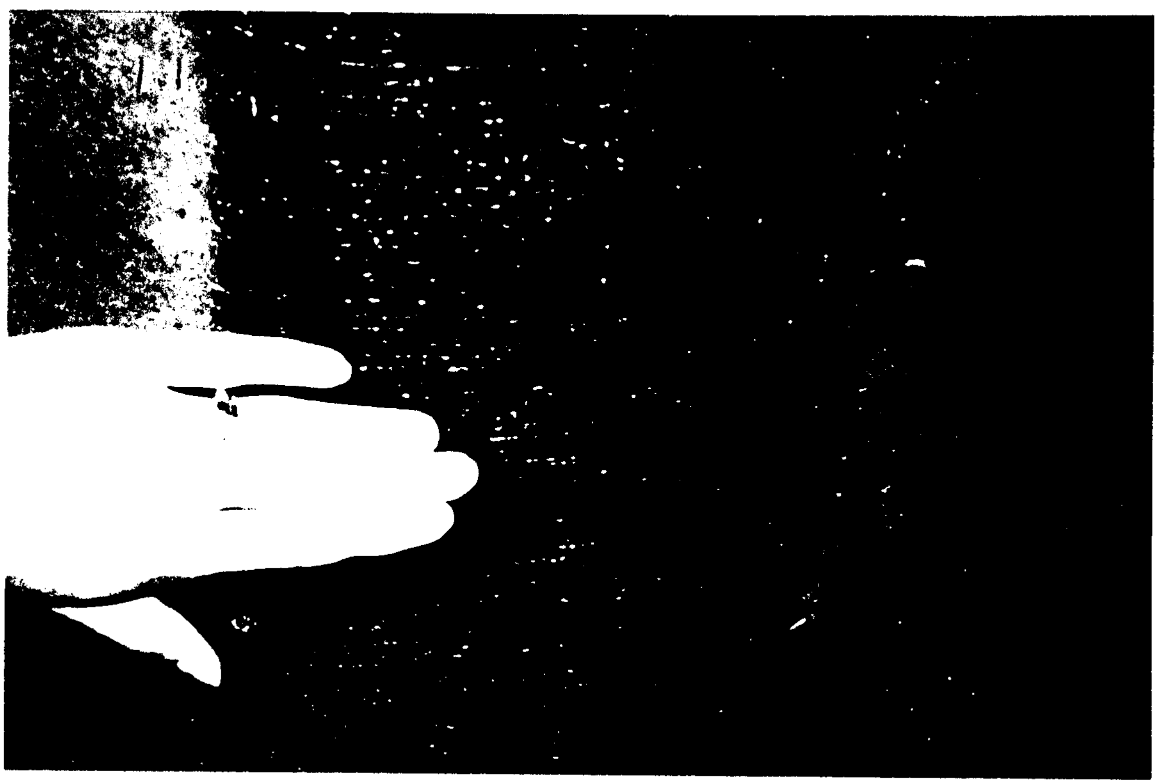

Figure B-2. Joint repair

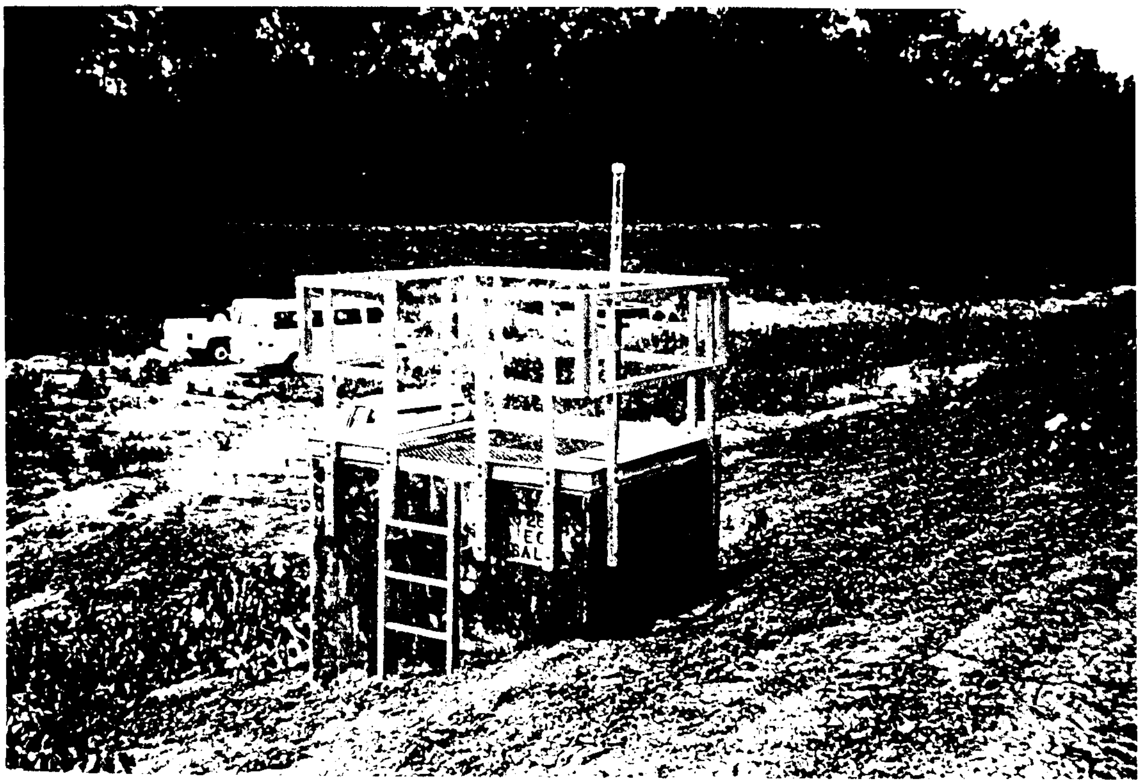

Figure B-3. Handrail, grating, and ladder fabricated from FRP materials

deflections the gate was allowed and limited stress in the gate to a percentage of the ultimate tensile strength of the FRP material.

c. The design was performed under a subcontract by McDonnell-Douglas Corporation. The resulting design was a combination of FRP materials and steel. For many applications the fact that FRP's are lightweight is advantageous and is a critical aspect in using these types of materials. The weight of the wicket gates was a design parameter because the gate had to be heavy enough so that it would not become buoyant under flow conditions. Based on this parameter a decision was made to use a combination of steel and FRP components. An exploded view of the composite wicket gate is shown in Figure B-4.

d. As can be seen in Figure B-4 the main framing member of the gate is made of steel. Steel was used for this member for two reasons. First, the steel would provide the stiffness required for the gate to meet the deflection required in the specification and second it would provide a suitable means for connecting the hydraulic arm to the gate. The remaining components are made of a glass/vinylester composite material. These components include the skin plates, the stiffeners for the skin plates, and the end sections of the gate.

B-4. Development and Demonstration of FRP Composite Materials Under the CPAR Program

Concurrently with the development of this ETL, several projects concerning FRP composite materials for civil engineering applications were being conducted under the Corps of Engineers Construction Productivity Advancement Research (CPAR) Program. The composites technologies being developed as part of these CPAR projects may be applicable to future Corps construction or maintenance activities. In order to provide an awareness of these projects and the technologies being developed and demonstrated, brief descriptions of the various ongoing projects are provided below. For additional information (including the participating Laboratory Point of Contact) about these or other additional CPAR projects regarding composite materials, contact HQUSACE element CERD-C.

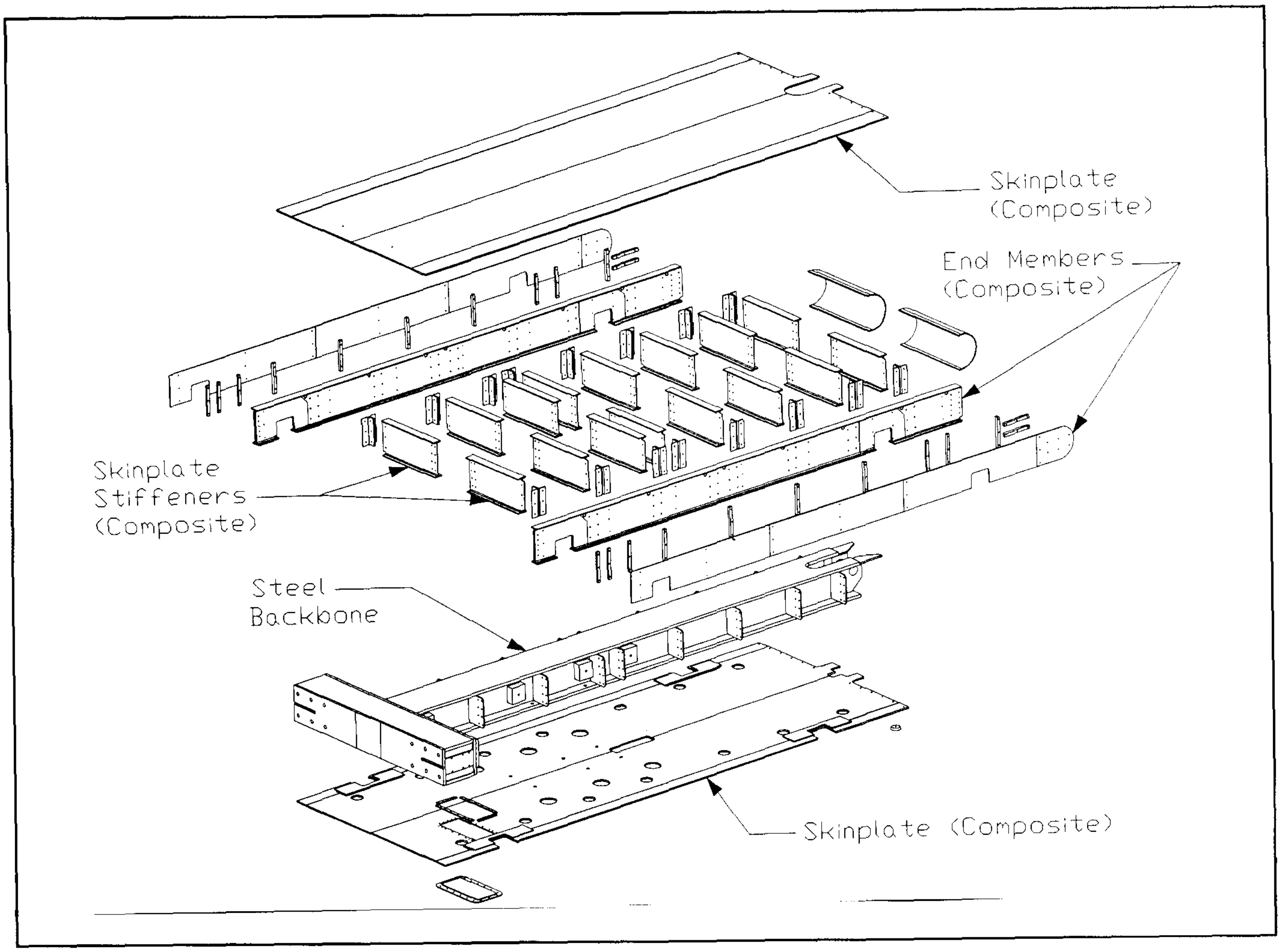

Figure B-4. Exploded view of composite wicket gate

a. Demonstration of advanced composite cables for use as prestressing in concrete waterfront structures.

(1) The objective of this project is to demonstrate the satisfactory performance and overall economy of advanced composites used as prestressing cables in concrete construction for civil-works-type structures in corrosive environments (e.g., splash zone areas, marine/saltwater exposures, water immersion, etc.). The product of the research will be advanced composite cables for use as prestressing elements in concrete structures for corrosive environments. Material specifications and design and construction guidance for the use of these advanced composite cables as prestressing structures in corrosive environments will also be developed.

(2) The Laboratory partner for this project is the U.S. Army Construction Engineering Research Laboratories (USACERL). The Industry/Academia partner is the South Dakota School of Mines and Technology. Industry/Academia partner participants include Amoco Performance Products, Owens-Corning, Neptco Inc., and the Composites Institute.

(3) To demonstrate the composite prestressing cables, a 12.2-m (40-ft) long by 5.5-m (18-ft) wide demonstration pier was selected for construction at the Navy Facilities Engineering Service Center (NFESC) in Port Hueneme, CA. Figure B-5 shows the basic layout and dimensions of the pier construction. The pier deck was designed to withstand a 1.0×10^6 newtons (225 kips) load over a 0.76-m (30-in.) square area (based on Navy requirements where their heavy cranes are in operation). Carbon-fiber reinforcing rods and cables were fabricated for the prestressing applications. Prestressed concrete

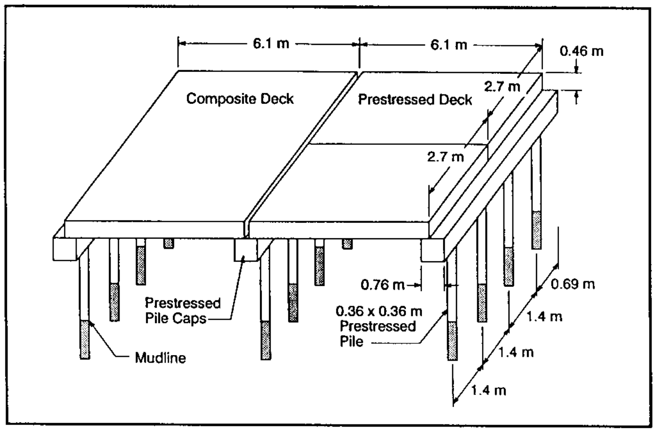

Figure B-5. Diagram of demonstration pier construction

piles [0.36 × 0.36 m (14 × 14 in.) square and 18.3 m (60 ft) long] and pier deck sections [each section was 6.1 m (20 ft) long by 2.7 m (9 ft) wide by 0.46 m (18 in.) thick] were fabricated using a pretensioned mode. One pile and deck section was tested in the laboratory to ensure that these elements met the design criteria. Glass-fiber-reinforced cables were fabricated and tested relative to design load criteria (the glass-fiber-reinforced composite cables were used in the pile caps in a posttensioned mode). The piles and deck sections were shipped to NFESC. After driving the piles, the pile caps were fabricated onsite and posttensioned. The prestressed deck sections were then placed onto the piles to span one of the bays. As an extra to the project, an all-composite deck section was fabricated using off-the-shelf pultruded composite structural elements and placed on the pile to span the second bay. The construction phase is now completed. Load testing and performance monitoring of the pier structure is under way. The project completion date is December 1995.

b. Demonstration of a full-scale concrete bridge deck reinforced with FRP composite reinforcing bars.

(1) The objective of this project is to demonstrate the advantages of the use of specially designed FRP composite reinforcing bars to improve the construction productivity and long-term durability (corrosion resistance) of reinforced concrete bridge decks. (Successful use of FRP composite reinforcing bars in a full-scale bridge deck will help demonstrate the potential for the use of FRP reinforcing bars in other concrete structures as well.) The product of the research will be FRP composite reinforcing bars for the reinforcement of concrete structures. Material specifications, design, and construction standards will be developed for the use of FRP composite reinforcing bars.

(2) The Laboratory partner for this project is USACERL. The Industry/Academia partner is West Virginia University--Center for Constructed Facilities. Industry/Academia partner participants include West Virginia Department of Highways and International Grating.

(3) During the course of the project, the following activities have been completed. Fatigue testing of concrete deck sections reinforced with composite reinforcing bars was completed in the laboratory. In cooperation with the West Virginia Department of Highways, a bridge was selected for the demonstration construction of a replacement deck using composite reinforcing bars. The bridge is on County Route 27/3 over Buffalo Creek near McKinleyville, WV. Preliminary designs for the bridge deck have been initiated. Final designs should be completed by early 1995 with construction completed by the fall of 1995. The project completion date is scheduled for May 1996.

c. Development and demonstration of hybrid, advanced design composite structural elements.

(1) The objective of this project is to develop, test, and demonstrate optimized, advanced design composite structural components (beams, trusses, profile shapes, panels, etc.) for civil engineering applications. The product of the research will be optimized composite structural components (beams, trusses, profile shapes, panels, etc.) for civil engineering applications.

(2) The Laboratory partner for this project is USACERL. Laboratory participants on this project include the U.S. Army Cold Regions Research and Engineering Laboratory (USACRREL) and the NFESC. The Industry/Academia partner is West Virginia University--Center for Constructed Facilities. The Industry/Academia participant for this project is the Composites Institute.

(3) This project is in its initial stages of execution. Three demonstration projects have been targeted: a salt storage shed, a pier deck section, and an observation tower. Theoretical optimization of structural composite shapes was initiated. A total of 8 beams, 8 columns, and 2 deck shapes will be optimized and tested. One half of these shapes will be based on existing die shapes with optimized fiber architecture. The other half will be optimized for both shape and fiber architecture

(i.e., orientation and arrangement). The project completion date is scheduled for March 1997.

d. Development and demonstration of polymer composite piling and sheet pile systems.

(1) The objective of this project is to develop, test, and demonstrate high-performance, polymer composite structural pilings, fender pilings, and sheet pile (bulkheads) for marine/waterfront civil engineering structures. The product of the research will be high-performance, composite structural, fender and sheet pile systems for marine/waterfront civil engineering applications. Material standards, specifications, and design protocol for each type of piling system will also be developed.

(2) The Laboratory partner for this project is USACERL. Laboratory participants include USACRREL, the U.S. Army Engineer Waterways Experiment Station (USAWES), and NFESC. The Industry/Academia partner is Rutgers University. Industry/Academia participants include the Composites Institute and the New York/New Jersey Port Authority.

(3) This project is in its early stages of execution. Mechanical, physical, and cost performance goals for each type of piling system have been formulated. Composite piling systems are being fabricated to meet these target goals. The fabricated systems will be tested in the laboratory to ensure performance with the most promising systems demonstrated in full-scale field constructions. The project completion date is currently scheduled for March 1997.

e. Development and demonstration of advanced composite materials systems to enhance/protect or repair/upgrade reinforced concrete civil engineering structures.

(1) The objective of this project is to develop, test, demonstrate, and commercialize advanced composite materials systems for in-place strengthening, repair, or upgrade of existing concrete civil engineering structures including columns, beams, and decking. Systems developed in this CPAR project will enhance structural protection against seismic damage as well as rehabilitate or upgrade deteriorated civil engineering structures. The end product of this research effort will be fiber-reinforced (glass and/ or carbon fibers) polymer composite material systems for the repair and/or upgrading of concrete columns, beams, and decking used in civil engineering structures (e.g., bridges and parking decks). Materials standards, specifications, and design protocols will be developed for each type of strengthening system.

(2) The Laboratory partner for this project is USACERL. Laboratory participants include USACRREL, USAWES, and NFESC. The Industry partner is the Composites Institute. Industry participants include the American Concrete Institute, the American Society of Civil Engineers, the California Department of Transportation (CALTRANS), and the Federal Highway Administration.

(3) This project is currently in its initial stages. A project "kick-off" meeting was held in February 1995. The project completion date is scheduled for December 1997.