Design of FRP Bridges

Forest Service Manual 7720.04a requires approval by the regional engineer for designs of all "major and complex" trail bridges. All FRP bridges are considered to be complex. Each forest is responsible for its decision to use FRP materials. The bridge must be designed by a qualified engineer experienced in the design of trail bridges and the use of FRP materials. Other jurisdictions may have different requirements—know the requirements you need to meet.

Design Specifications for FRP Pedestrian Bridges

By early 2006, no design specifications for FRP pedestrian bridges had been approved in the United States. E.T. Techtonics, Inc., has submitted *Guide Specifications for Design of FRP Pedestrian Bridges* to the American Association of State Highway Transportation Officials (AASHTO) for approval. These guide specifications are in appendix B. Other professional organizations are addressing the recommended use and specifications of FRP materials and products using them, including the American Society of Civil Engineers (ASCE), the American Society of Testing and Materials (ASTM), and the FHWA.

Design and material specifications are now available only through manufacturers of FRP materials. In the absence of standard material and design specifications, manufacturers' specifications should be followed. There is no way to validate the information manufacturers supply other than by performance history or testing. Errors may exist. Different manufacturers use different resin-to-reinforcement formulas when constructing FRP members, so material properties will differ. The designer should be certain to use the manufacturer's design manual and specifications.

Design Concerns

With any new technology, methods must be developed to predict long-term material properties and to predict structural behavior based on those properties. This information is incorporated in specifications for design parameters, material composition and variance, size tolerances, and connections. Methods for inspection and repair also are derived from long-term testing and observation.

Although specification development and further testing is in progress, standard FHWA specifications and ASCE Load Resistance Factor Design (LRFD) procedures won't be available for the next 5 to 6 years, as reported by Dan Witcher of Strongwell and chairman of the Pultrusion Industry Council's Committee on LRFD Design Standards. Two leading manufacturers of FRP structural products, Strongwell, and Creative Pultrusions, Inc., have specifications and design safety factors listed on their design manual CDs. Appendix G has contact information for these manufacturers.

The designer should be aware that shear stresses add more deflection to loaded beams than the classic flexural deflection. Temperatures above 80 degrees Fahrenheit reduce allowable stresses and FRP materials may sag or elongate under sustained loading (time-dependent effects, called *creep*). A temperature of 125 degrees Fahrenheit decreases FRP strength by 30 percent and stiffness by 10 percent (Creative Pultrusions, Inc. 2004; Strongwell 2002). The design needs to consider the service temperature range. FRP members must be designed for lower allowable stresses (no more than 40 percent of the ultimate allowable stress) to minimize creep.

Lateral stability needs to be addressed for different types of bridge configurations. For spans of 30 feet or more, side-truss FRP bridges should have outriggers at all panel points (see figure 8) to provide lateral restraint for the compression flanges. FRP bridges longer than 60 feet that are used by pack trains should have a deck-truss design. That design places the trusses under the deck, increasing restraint on the compression flanges (see figure 7) and increasing the frequency characteristics of the bridge, an important consideration for the live loads generated by pack trains.

Attention to details can help reduce performance problems with FRP bridges:

- Avoid hollow tubes with walls less than ¼ inch thick.
- Fill at least 12 inches of each end of hollow tubes with solid material.
- Provide a drain hole at the bottom of the tube so trapped water can drain.

Bridges made with FRP materials perform differently than bridges made with steel, concrete, or wood. Take these differences into account when designing bridges with FRP materials.

Other Concerns

FRP bridges have many different design considerations. Pack trains may produce vibrations that match the fundamental frequency of the bridge, which may cause the bridge to fail. The natural frequency of the bridge and live loads should be taken into account when ordering the structure. Because of FRP's typically low modulus of elasticity, most designs will be controlled by deflection limitations and not strength requirements. Although the criterion for deflection is somewhat arbitrary, AASHTO guidelines for pedestrian bridges recommend that the deflection of members (in inches) be less than the length of the supporting span divided by 500 (L/500). FRP manufacturers and designers recommend L/400, which would allow more deflection.

Inspecting and Maintaining FRP Bridges

Many types of inspections can be used when rating the condition of FRP pedestrian bridges. This section describes nondestructive testing (NDT) methods, required equipment, and general procedures for conducting the inspections. The NDT methods are listed in order of increasing complexity. The last six require specialized experience or equipment and should be performed by consultants under contract. This information was gathered as part of a study by the Construction Technology Laboratories for inspection of FRP bridge decks (National Cooperative Highway Research Program, Project 10-64, *Field Inspection of In-Service FRP Bridge Decks*). Inspections are required at least every 5 years for Forest Service trail bridges.

Most routine FRP bridge inspections use the two primary methods of visual and tap testing. More complex methods should be adopted only if the primary methods are not adequate to observe or assess unusual conditions. The cost to inspect a bridge using some of the more complex methods may be more than the cost of replacing the bridge.

Visual Testing

Visual testing (VT) is the primary NDT inspection method adopted by bridge inspectors, and is well suited for assessing the condition of FRP pedestrian bridges. The basic tools required are a flashlight, measuring tape, straightedge, markers, binoculars, magnifying glass, inspection mirrors, feeler gauges, and a geologist's pick. Visual inspection generally detects only surface defects, such as cracking, scratches, discoloration, wrinkling, fiber exposure, voids, and blistering.

To help detect defects or cracking that might go unnoticed with VT, a static or dynamic live load test can be done. Loading the bridge with an all-terrain-vehicle or any live load can help reveal hidden cracks and undesirable movement.

Tap Testing

Tap testing is the second most common type of NDT performed on an FRP bridge. Tap testing is a fast, inexpensive, and effective method for inspecting composites for delamination or debonding. The mechanics of the test are analogous to "chain drag" delamination surveys used to inspect reinforced concrete bridge decks, or for inspections of wood timbers by sounding with a hammer.

The inspector taps the surface with a hammer or coin and listens for a distinctive change in frequency, indicating a void or delamination. A clear, sharp ringing indicates a well bonded structure, whereas a dull sound indicates a delamination or void. Geometric changes within the structure also can produce a change in frequency that may be interpreted erroneously as a defect. The inspector must be familiar with the features of the structure. Tap testing does not require NDT certification. A bridge engineer or inspector can perform this NDT method with very little training.

Thermal Testing

Thermography is effective for identifying discontinuities close to the surface, such as delamination, debonding, impact damage, moisture, and voids. Thermography uses an ambient or artificial heat source and a heat-sensing device, such as an infrared (IR) camera, to measure the temperature variation within the sample. Heat can be applied to the surface by natural sunlight or by a pulsed light source. An IR camera measures the temperature variation of the object. Subsurface variations such as discontinuities or voids in the material will cause slight changes in the wavelength of IR energy that radiates from the object's surface. These discontinuities in the material or emissivity differences can be detected by IR cameras.

Acoustic Testing

Acoustic testing relies on changes in sound waves to reveal defects under loading. A structure under certain load levels produces acoustic sound (known as an acoustic emission), usually between 20 kilohertz and 1 megahertz. The emission is from the stress waves generated because of deformation, crack initiation and growth, crack opening and closure, fiber breakage, or delamination. The waves come through the solid material to the surface, where they can be recorded by one or more sensors or transducers. Acoustic tests involve listening for emissions from active defects and are very sensitive when a structure is loaded.

Ultrasonic Testing

Ultrasonic testing uses high-frequency sound in the range of 20 kilohertz to 25 megahertz to evaluate the internal condition of the material. This method involves applying a couplant (typically water, oil, or gel) to the area to be inspected and scanning the area with a transducer (or probe) attached to the ultrasonic testing machine. The couplant serves as a uniform medium between the surface of the area being scanned and the transducer to ensure the transmission of sound waves. Discontinuities that can be detected include delamination, debonding, resin variations, broken fibers, impact damage, moisture, cracks, voids, and subsurface defects. Unlike visual inspection, tap testing, or thermography, ultrasonic testing requires a high level of expertise to conduct the test properly and to interpret the data.

Radiography

Radiography uses a penetrating radiation source, such as X-rays or gamma rays, and radiographic film to capture images of defects. Differential absorption of the penetrating radiation by the object will produce clearly discernible differences on radiographic film. Radiography requires access to both sides of the structure, with the radiation source placed on one side and the film on the other. Typical discontinuities that can be detected include some delaminations and some debonds (depending on their orientation), voids, resin variations, broken fibers, impact damage, and cracks. Radiography equipment can be hazardous if not handled or stored properly. This method requires a high level of skill to conduct the test and to evaluate the images.

Modal Analysis

Modal analysis evaluates a structure's condition based on changes in the structure's dynamic response. The structure is instrumented with an array of accelerometers and dynamic load tests are performed to extract modal parameters with selected frequencies and mode shapes. This method requires capital investment for sensors and data acquisition equipment, staff training, and a relatively high skill level to set up the equipment and to reduce and interpret the data. This method should be used only if other techniques are unable to address concerns about hidden damage and the overall structural performance of an FRP bridge.

Load Testing

During load testing, a bridge is instrumented with sensors such as strain gauges, accelerometers, and displacement sensors before being subjected to a known live load with a specific loading pattern. The instruments can measure the response of the structure during load tests and help determine the bridge's long-term structural health. Load testing requires investing in sensors and data acquisition equipment, and the development of the skills needed to set up the equipment and to reduce and interpret the

data. This method is used only if other methods are unable to address concerns about hidden damage and the overall structural performance of an FRP Bridge.

Comparison of Inspection Methods

Visual testing is the simplest and most commonly used method. It allows the inspector to rapidly detect gross imperfections or defects such as cracks, delamination, or damage from impacts. Visual testing often can help detect imperfections, such as lack of adhesive, edge voids, discoloration, and deformation. To a trained inspector, visual testing immediately identifies areas needing more detailed examination. This technique requires interpretation, so inspectors should be trained to know what they are looking for and what any variation might mean to the strength and reliability of the bridge component. Visual testing cannot:

- Quantify the extent of damage
- Inspect components that are not visible

Tap testing or *sounding* is another excellent and easy-to-use method for inspecting FRP materials for delamination. The inspector listens for any change in sounds while tapping FRP surfaces. Although tap testing can be used on pultruded sections, it is less effective in detecting delaminations or debonds. Most common problems on FRP bridges can be identified using a combination of tap testing and visual testing.

Neither tap testing nor visual testing requires specialized equipment. With some training, both methods are easy to incorporate into an inspection program. Other testing methods such as thermal testing, acoustic testing, ultrasonic testing, radiography, modal analysis, and load testing are much more complex, expensive, and time-consuming.

Qualifications for Inspectors

The Forest Service inspector and team leader qualifications in the Forest Service Manual, section 7736.3, *Qualification of Personnel for Road Bridges*, should be used. FRP pedestrian bridges are considered complex trail bridges. Inspectors also should have additional qualifications and experience so they can identify the need for advanced inspection methods, such as acoustic, ultrasonic, or radiographic testing, and interpret the test results. Specialized NDT engineers, employed by consultants, may need to perform these inspections.

Visual Signs of Damage and Defects

Inspectors need to look at the structure as a whole as well as at specific spots. Particular problems to look for are discussed below.

Side Trusses

All trusses should be vertical and should not have any buckling (figure 27) or out-of-plane bowing (figure 28). Either condition would be an indication of a buckling failure. The nature of FRP materials will cause such

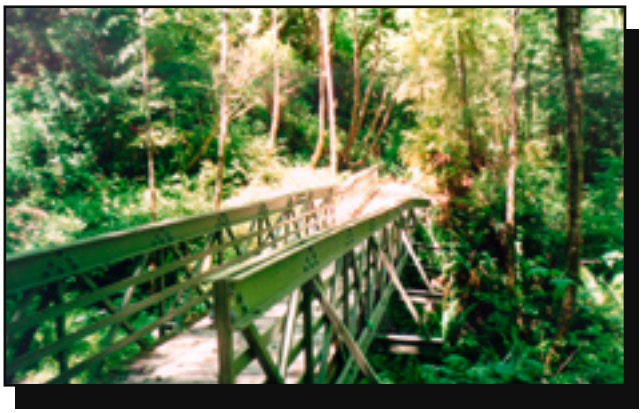

Figure 27—This FRP bridge in Redwood National Park began to fail when a loaded mule train was halfway across. No one was injured.

Figure 28—The top chord bowed on the left side truss of the Staircase Rapids Trail Bridge in the Olympic National Forest.

problems to become worse over time. Buckling is a particular concern if the structure will be subjected to long-term loads such as snow loads.

Deflection

Trusses are typically designed with a slight arch that should be visible. If the arch is not present, the plans should be reviewed and compared to the structure to see if the deflection is within design specifications. Excessive deflection could be an indication of loose bolts or connection failure. The deflection should be noted and monitored closely.

Connections

All connections should be inspected carefully for cracking (figure 29). This is especially significant for connections secured with a single bolt. A two-bolt connection allows the second bolt to take up some of the load of a ruptured connection. All bolts are load bearing, so any loose connections must be tightened. Overtightening bolts may crack the FRP member, affecting its strength and structural stability.

Figure 29—This joint at the top of a vertical post was damaged when bolts were overtightened. The material was thinner than the $\frac{1}{4}$ inch minimum now recommended.

Blistering

Blistering appears as surface bubbles on exposed laminated or gel-coated surfaces. In the marine industry, blisters generally are attributed to osmosis of moisture into the laminate that causes the layers to delaminate, forming bubbles. FRP bridge members are not as thin as boat hulls. Osmosis to a degree that would cause blistering is rare. Trapped moisture subjected to freeze-thaw cycles might cause blistering, but the blistering probably would affect just the outside layer of the material without affecting the material's structural performance.

Voids and Delaminations

Voids are gaps within the member. They can't be seen if the composite laminate resin is pigmented or if the surface has been painted or gel coated. If the void is large enough and continues to grow, it may appear as a crack on the surface. Often, voids are hidden and can lead to delamination over time. End sections of FRP

materials can delaminate during construction if connections are overtightened, causing the laminations to separate (see figure 29).

Discoloration

- Discoloration of the FRP material (figure 30) can be caused by a number of factors, including:

Figure 30—The lower section of this member of an FRP bridge is discolored because the coating that protected it from ultraviolet light wore off.

- Chemical reactions, surface deterioration because of prolonged exposure to ultraviolet light or exposure to intense heat or fire.
- Crazing and whitening from excessive strain, visible mainly on clear resins.
- Subsurface voids that can be seen in clear resins because the material was not completely saturated with resin during manufacture.
- Moisture that penetrates uncoated exposed resin, causing freeze-thaw damage called *fiber bloom*.
- Changes in pigmentation by the manufacturer, although this is not a structural problem.

Wrinkling

Fabric usually wrinkles because of excessive stretching or shearing during wet out. Wrinkling is not a structural problem unless it interferes with the proper surface contact at the connection or prevents the surface veil from bonding to the internal material.

Fiber Exposure

Fiber may be exposed because of damage during transportation or construction (figure 31). Left unattended, the fibers would be susceptible to moisture and contamination, leading to fiber bloom.

Figure 31—This truss was damaged by dragging or improper handling.

Cracks

The face of an FRP member may be cracked because connections were overtightened (see figure 29) or the members were damaged by overloading (figure 32) or impact. Cracks caused by impact from vehicles, debris, or stones typically damage at least one complete layer of the laminated material.

Figure 32—The bottom chord was damaged by dynamic loads from ATV traffic, by bolts that were overtightened, or by overloading.

Scratches

Surface veils can be abraded from improper handling during transportation, storage, or construction. Scratches are shallow grooves on the FRP surfaces. These are usually just unsightly surface blemishes, but, if severe, they can develop into full-depth cracks. Scratches (see figure 31) are judged severe when they penetrate to the reinforcing fibers, where they can cause structural damage.

Repair and Maintenance

Damage found during inspections should be repaired. Evaluate the damage and contact the FRP manufacturer to discuss proper repair options. Some of the FRP manufacturers have developed repair manuals. Strongwell has published a *Fabrication and Repair Manual* that covers minor nonstructural repairs. The manual covers maintenance cleaning, sealing cuts and scratches with resin, splicing cracks, filling chipped flanges with resin, filling holes, and repairing cracks with glass material impregnated with resin.

FRP bridges need to be maintained annually to ensure that they remain in service. Cleaning decks, superstructures, and substructures helps to ensure a long life. Resealing the surface veil with resin improves resistance to ultraviolet radiation and helps prevent moisture from penetrating and causing fiber bloom. Polyurethane or epoxy paint can be applied to parts that will be exposed over the long term. If cracks, scratches, and other abrasions are not repaired, the FRP member will be susceptible to fiber bloom and deterioration.

Bridges Tested at the Forest Products Laboratory

In the fall of 1997, the FRP Trail Bridge Project Team selected two sites for fiberglass trail bridges. The first site was in the Gifford Pinchot National Forest northeast of Portland, OR, 1½ miles from the Lower Falls Creek Trailhead. A 44-foot-long by 3-foot-wide trail bridge (overall length is 45'6") was needed. This area has extreme snow loads (250 pounds per square foot). This bridge was funded by the FHWA and designed by their Eastern Federal Lands Bridge Design Group in consultation with E.T. Techtonics, Inc.

The second site was in the Wallowa-Whitman National Forest near Enterprise, OR, at the Peavine Creek Trailhead. A 22-foot-long by 6-foot-wide pack bridge was needed to fit abandoned road bridge abutments. The snow load at this site, 125 pounds per square foot, is more typical of Forest Service locations. This bridge was funded by the Forest Service and designed by E.T. Techtonics, Inc. The fiberglass channel and tube shapes for both bridges were manufactured by Strongwell and supplied by E.T. Techtonics, Inc.

Design Overview

The Falls Creek Trail Bridge was designed in accordance with AASHTO's Standard *Specifications for Highway Bridges* and *the Guide Specifications for Design of Pedestrian Bridges*.

Neither specification deals with FRP bridges, because specifications have not yet been approved—a major impediment for trail bridge designers. Additional guidance and design techniques were developed from sources in the FRP composite industry.

The *Design Manual for EXTREN Fiberglass Structural Shapes* (2002), developed by Strongwell, is a good source of information on the individual structural components. Because the FRP composite sections were patterned after shapes used in the steel industry, some guidance and design techniques were developed based on the *Manual of Steel Construction* (1989) from the American Institute of Steel Construction. In addition, E.T. Techtonics, Inc., helped interpret and modify existing information, provided test data on the strength of joints and connections, suggested improvements (such as filling the ends of hollow members), and reviewed the final design.

Each structural member of the bridge was designed with respect to standard strength parameters, including allowable tension, compression, bending, and shear stresses, as well as combined stresses due to axial forces and moments acting together. Primary loads included dead, snow, and wind loads. The design forces and moments were the maximum values generated by analysis.

Allowable design stresses were determined by dividing the ultimate strength of the FRP material (the strength at which it would break based on the manufacturer's data) by the following safety factors:

Design stress	Safety factor
Tension and bending	2.5
Compression	3.0
Bearing	4.0

To ensure that the bridge could support the anticipated snow loads, the stresses during the test at the Forest Products Laboratory were limited to no more than 30 percent of the ultimate bending and tensile strength. A full description of the design process, member stresses, and equations is in appendix H.

Materials

The structural sections making up the trusses for the two trail bridges were manufactured by Strongwell, a major

manufacturer of fiberglass structural shapes, and came from the company's EXTREN line. EXTREN products contain glass fibers embedded in an isophthalic polyester resin (see glossary in appendix A). Each member also included a surface veil layer of polyester nonwoven fabric and resin for protection from ultraviolet exposure and corrosion. The decking also was a Strongwell product. It included a 6-millimeter (¼-inch) EXTREN sheet with a gritted surface on top of DURAGRID I-7000 25-millimeter (1-inch) grating. The composition of the grating is similar to that of the structural shapes except that the grating contains a vinyl ester resin binder. All of the FRP composite sections were manufactured using the pultrusion process.

Only two other materials were used in the superstructure of these bridges. The sections were connected with ASTM A307 galvanized bolts. The superstructures were attached to the foundations by ASTM A36 galvanized-steel anchor bolt clip angles.

Simulated Design Live Load Testing

Fiber-reinforced composite materials have different structural properties than conventional construction materials, such as steel, concrete, and timber. To verify the design of the 44-foot bridge, and to investigate the behavior of both the 22- and 44-foot bridges under actual use conditions, we tested both bridges under harsh environmental conditions while they were subjected to their full design loadings.

After the FHWA completed the design of the 44-foot bridge in the spring of 1998, materials for both bridges (figure 33) were shipped to the Forest Products Laboratory in Madison, WI, for full-scale testing. Weather conditions in Madison are severe, ranging from –30 to 100 degrees Fahrenheit. Humidity is relatively high, averaging about 65 percent.

Figure 33—Two FRP bridges—one 22 feet long (left) and the other 44 feet long (right)—were tested at the Forest Products Laboratory in Madison, WI.

The materials (figure 34) for the 22-foot bridge weighed about 1,700 pounds. The materials for the 44-foot bridge weighed about 4,400 pounds. A five-person crew (two representatives from E.T. Techtonics, Inc., two engineers from the FHWA, and one engineer from the Forest Service) began constructing the 22-foot bridge on an FPL parking lot at about 2 in the afternoon. Three hours later, the bridge was completed. Construction of the 44-foot bridge began at about 8 the next morning and the construction was completed by early afternoon. A small forklift set both bridges onto 10-foot-long concrete traffic barriers, which served as bearing supports.

Figure 34—The materials for an FRP bridge after delivery to the Forest Products Laboratory.

The bridges were installed in a back parking lot and loaded to their full design loading (250 pounds per square foot for the 44-foot bridge and 125 pounds per square foot for the 22-foot bridge). Plywood boxes constructed on each bridge deck and filled with landscaping rock provided the load. Rock was 30 inches deep on the deck of the 44-foot bridge and 15 inches deep on the deck of the 22-foot bridge.

Deflection gauges (figure 35) were placed at the second panel point (4/9ths of the span) and at middle of the span of both trusses on the 44-foot bridge. Refer to appendix D for a drawing showing the location of the deflection and strain gauges. Because the bridge has nine 5-foot panels, the midspan deflection gauge is in the middle of the center panel. The 22-foot bridge has four 5-foot, 6-inch panels so the deflection gauges were placed at the center panel point of both trusses.

Figure 35—The typical setup of a deflection gauge used to test bridges.

Deflection measurements were taken immediately after loading and at several intervals during the first day. Readings were taken daily at first, then weekly and monthly after movement stabilized. Deflection measurement continued for 7 days after the test loads were removed. Neither of the bridges completely returned to the original, unloaded deflection.

Bridge deflections were monitored from October 1998 until August 1999. Refer to appendix D for data and graphs. The bridges performed well under load. Actual deflections closely matched the design deflections. When the bridges were disassembled, they had only minor problems.

One hole in a two-bolt connection between hollow members elongated and cracked on the 22-foot bridge (figure 36). The elongation was caused by slightly mismatched holes in the connecting members. Bolt holes need to be very closely aligned when members are fabricated. During testing, only one bolt was engaged initially. That hole elongated and began to fail. When the hole had elongated enough so that the second bolt became engaged, the connection held, preventing complete failure. The member was replaced with an end-filled (solid) member with precisely drilled holes before the bridge was placed at its final location.

Figure 36—This tube cracked when bolts were overtightened on one of the bridges being tested at the Forest Products Laboratory.

Analysis of Test Data

The deflection of the 44-foot bridge increased gradually at a decreasing rate for the first 30 days of loading, before stabilizing at a deflection of about 1.25 inches at midspan and 0.90 inch at the second panel point. This deflection

was close to the calculated deflection of 1.30 inches at midspan. The deflection remained stable until about day 216 (May 3, 1999). At that point deflections began increasing at a slow, constant rate until day 280 (July 6, 1999) when the deflection increase accelerated. By day 289 (July 15, 1999), the deflection had again stabilized at about 1.49 inches.

The deflection of the 22-foot bridge followed much the same pattern. The wire used to measure deflection on side 2 was bumped while the bridge was being loaded, resulting in a slight difference in the deflections measured on each side of the bridge. The deflection graphs, although slightly displaced from one another are nearly identical for both trusses.

Fiberglass has a low modulus of elasticity (or stiffness) compared to other materials. When fiberglass is embedded in a polymer, the behavior of fiberglass is somewhat plastic—accounting for the gradual movement to the anticipated deflection over the first 30 days of the test.

As temperatures rise, fiberglass loses strength and stiffness. The increases in deflection correspond closely to increases in daytime temperatures in Madison. Information provided by Strongwell indicates that the ultimate stress can be reduced by as much as 30 percent when temperatures reach 125 degrees Fahrenheit and the modulus of elasticity can be reduced by 10 percent. Although reduced strength during hot weather concerned us during several weeks of the test period, real-life concerns would be minimal. Our design loading is snow load. The July and August pedestrian and stock loadings are brief and can be assumed to be no more than 85 pounds per square foot.

The bridges did not totally return to the unloaded condition because:

- The material is plastic and gradually reformed to the deflected shape.
- Some slippage occurred in the bolt holes at the bolted connections.

Refer to appendix D for data and graphs.

Disassembly and Installation at Field Sites

On August 8 and 9, 1999, the bridges were disassembled (figure 37) and all the components were visually inspected for damage and wear. The bridges were shipped to their respective sites for permanent installation in September of 1999. The 44-foot bridge was installed in the Gifford Pinchot National Forest during October of 1999. The 22-foot bridge was installed in the Wallowa-Whitman National Forest during the summer of 2000.

Figure 37—Disassembling an FRP bridge after testing at the Forest Products Laboratory.

Falls Creek Trail Bridge

A county detainee crew hand-carried the 4,400 pounds of materials for the 44-foot Falls Creek Trail Bridge in late September (figure 38). Components for a comparable steel-truss bridge would have weighed about 10,000 pounds. That material would have been extremely difficult to pack to the bridge site, because the individual steel members would have weighed up to 500 pounds.

Figure 38—Installing one of the tested FRP bridges at Falls Creek in the Gifford Pinchot National Forest.

The heaviest fiberglass members weighed 180 pounds. Even though these members were 45 feet long, they were flexible enough that they could be bent around tight corners of the trail.

The concrete abutments were cast during the first week of October 1999. An eight-person crew began installing the bridge the following week. Installation was completed shortly after noon of the second day. The bridge spans a very steep, sharply incised, intermittent channel about ¼ mile from a very popular scenic falls (figure 39). The Forest Service estimates peak use of this trail to be as high as 300 persons per day.

Figure 39—The Falls Creek Trail Bridge provides access to this waterfall.

Peavine Creek Trail Bridge

The 22-foot-long bridge was installed on the former site of a road bridge. The bridge was designed to be placed directly on the existing abutments. The site was accessible by a truck that delivered the materials and a small backhoe.

The bridge was built on the approach roadway and lifted in one piece onto the abutments. The bridge was constructed by the Wallowa-Whitman National Forest road crew and set in place in 1 day. Because the road crew was not familiar with FRP materials, they overtorqued the bolts, cracking several of the hollow tubes. These cracks, which have been monitored since installation, have closed slightly because of bearing compression of the FRP materials.

Reinspection

The bridges were reinspected during the fall of 2004. The cracks at the connections had not changed significantly and the members had a chalky appearance because the surface veil had developed fiber bloom. The Falls Creek Bridge had developed cracks at top post and at floor beam tie-down connections. Additional information is in the *Case Studies and Failures* section.