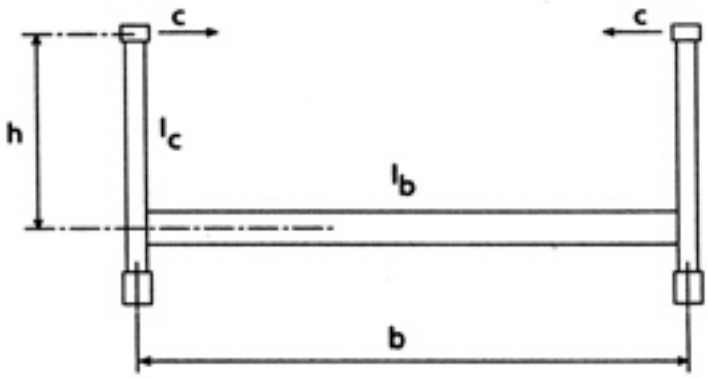
1/K FOR VARIOUS VALUES OF C/P_c and n

	n						
1/K	4	6	8	10	12	14	16
1.000	3.686	3.616	3.660	3.714	3.754	3.785	3.809
0.980		3.284	2.944	2.806	2.787	2.771	2.774
0.960		3.000	2.665	2.542	2.456	2.454	2.479
0.950			2.595				
0.940		2.754		2.303	2.252	2.254	2.282
0.920		2.643		2.146	2.094	2.101	2.121
0.900	3.352	2.593	2.263	2.045	1.951	1.968	1.981
0.850		2.460	2.013	1.794	1.709	1.681	1.694
0.800	2.961	2.313	1.889	1.629	1.480	1.456	1.465
0.750		2.147	1.750	1.501	1.344	1.273	1.262
0.700	2.448	1.955	1.595	1.359	1.200	1.111	1.088
0.650		1.739	1.442	1.236	1.087	0.988	0.940
0.600	2.035	1.639	1.338	1.133	0.985	0.878	0.808
0.550		1.517	1.211	1.007	0.860	0.768	0.708
0.500	1.750	1.362	1.047	0.847	0.750	0.668	0.600
0.450		1.158	0.829	0.714	0.624	0.537	0.500
0.400	1.232	0.886	0.627	0.555	0.454	0.428	0.383
0.350		0.530	0.434	0.352	0.323	0.292	0.280
0.300	0.121	0.187	0.249	0.170	0.203	0.183	0.187



Where: $C = \dfrac{E}{h^2\,[h/3I_c + b/2I_b]}$

l = Chord Panel Length
P_c = Buckling Load (= Max Chord T × F.S.)
n = Number of Panels

Reference: Galambos, T.V., *Guide to Stability Design Criteria for Metal Structures*, 4th ed., 1988, New York: John Wiley and Sons, Inc., pp. 515–529.

Figure 4—Transverse frame spring constant table for pedestrian bridges.—*From* Guide Specifications for Design of Pedestrian Bridges *Copyright 1997, by the American Association of State Highway and Transportation Officials, Washington, DC. Used by permission. Documents may be purchased from the AASHTO bookstore at 800-231-3475 or online at* http://bookstore.transportation.org.

Appendix I—Example Installation Instructions

Example installation instructions for the Falls Creek Trail Bridge.

Falls Creek Trail Bridge
45-Foot Bridge Assembly Instructions

(Gifford Pinchot National Forest)

GENERAL NOTES

After examining all parts and reviewing all documentation, be sure to account for each part that is listed under the parts list and shown in the plans. Also, verify that all necessary tools listed under *Tools Required* are available. Before beginning assembly operations note the following:

1. Assembly Instructions assume the use of $\frac{3}{4}$-in bolts unless otherwise noted.

2. Use drift pins to align holes during assembly. When necessary, a rat-tail file may be used to slightly enlarge holes.

3. Each connection consists of a bolt with a flat washer under the head and a flat washer, lock washer, and nut on the threaded end.

4. All bolt heads are on the inside face of the members except those attaching to the bottom chord. The bottom chord bolt heads are on the outside of the chords. If desired, the bottom chord bolts can also have their heads on the inside face.

5. Generally all components should first be installed with the connections made "finger tight." After all parts are assembled and proper alignment is obtained, tighten all bolts securely. Tighten all nuts until lock washers are compressed to a flat position. ***Do not over tighten.***

6. Bottom chords (G2 and G3) have occasional holes in the bottom flange only. The chords must be installed with the holes on the bottom to facilitate the attachment of the horizontal bracing.

7. Vertical posts (P1, P1A, and P2) have pilot holes in their inside face only. The posts must be installed with the holes facing inward to facilitate the attachment of the midrails.

8. Crosspieces (C1 and C2) have holes in their top flange only. The crosspieces must be installed with the holes on the top to facilitate the attachment of the decking.

9. Compression diagonals (DC1) are installed sloping upward toward the center of the span and placed against the inside channel of each chord.

10. Tension diagonals (DT1) are installed sloping downward toward the center of the span and placed against the outside channel of each chord. The Tension Diagonals in the center span (DT2) can slope in either direction and can be installed against either channel.

11. Whenever possible, orient the members such that any labels or other marking on them is hidden by connections with other members.

To assure proper alignment of connections, it is critical that sufficient support and alignment be maintained during assembly operations. All temporary supports must be level from side to side and at the proper elevation so as not to introduce a twist or a wiggle into the structure. Regularly sight along the chords during assembly operations to ensure the alignment conforms to a reasonable degree of straightness. Shims should be used at as many points along the bottom chord as is convenient to adjust the alignment. They can also be used to provide the camber that is built into the span. The following measurements should be used to set the proper camber. They are measured from a straight line connecting the abutments to the bottom of the bottom chord. At each post starting at either end they are: 0 in, $\frac{1}{2}$ in, $\frac{7}{8}$ in, $1\frac{1}{8}$ in, $1\frac{1}{4}$ in, $1\frac{1}{8}$ in, $\frac{7}{8}$ in, $\frac{1}{2}$ in, 0 in.

ASSEMBLY STEPS

1. Construct temporary supports at two or three locations. Temporary supports at the quarter-points of the span or two supports centered 5 ft from the center of the span should suffice. Construct all supports wide enough to accommodate the span (4 ft minimum) and strong enough to carry the weight of the bridge in addition to workers. The supports must be placed and erected in such a manner as to not interfere with the assembly operations. *Note:* The horizontal bracing will be attached after the supports are removed.

2. Lay out bottom chord girders (G2 and G3) in correct pairs on supports. Note: flanges with holes in them go on bottom. Also, holes in bottom flange of outside girders (G3) are spaced closer together than those on the inside girders (G2).

3. Attach stub posts (SP1) and bottom chord girders using $\frac{1}{2}$- by 6-in hex bolts. Note: The stub posts should be oriented such that the plugged end is on top and the girders are 4 in apart. Finger tighten nuts. Loosely attach the steel anchor clip angles (A1 and A2) using one $\frac{3}{4}$- by 7-in bolt per angle. *Note:* Place the 4-in leg of the clip angles to the bottom chord and the slot in the 5-in leg over the anchor bolts. Bottom chords can remain upright on the supports on their own at this point.

Align bottom chords on supports. Shim to level if necessary and also to provide proper camber (See *General Notes*).

4. Attach four vertical posts (two P1A at midrail splices, and two P2 at ends) per truss to bottom chord by sliding between the channels and connecting with $\frac{3}{4}$- by 6-in hex bolts. Finger tighten nuts. *Note:* Orient posts such that the ends with two sets of $\frac{13}{16}$-in-diameter holes are at the bottom, the plugged ends are at the top, and the pilot holes are facing toward the deck. Individual bottom chords may not be particularly stable until the next step is completed.

5. Attach the crosspieces (C1) to the vertical posts (P1A) and end crosspieces (C2) to the end vertical posts (P2) using $\frac{3}{4}$- by 4-in hex bolts. Finger tighten nuts. *Note:* Point the bolt heads toward the nearest end of the bridge and orient them so that the holes are all in the top flanges. Structure now should be somewhat stable.

Adjust alignment horizontally and vertically. *Note:* Adjustments are easier to make before additional weight is added.

6. Attach horizontal bracing (H1 and H2) to the bottom chords wherever accessible with $\frac{1}{2}$- by $3\frac{3}{4}$-in hex bolts with the nuts on the underside. Finger tighten nuts. *Note:* H2 braces are interchangeable, but H1 braces must be installed at the ends. If difficult to access, some bracing can be attached later.

7. Attach the intermediate crosspieces (C2) to the stub posts using $\frac{3}{4}$- by 4-in hex bolts. Finger tighten nuts. *Note:* Point the flanges and the bolt heads toward the nearest end of the bridge. Examine the center decking panel (D2) to determine which side of the center stub posts to put the center Intermediate crosspiece. The connection holes are slightly to one side of center and the intermediate crosspiece must be installed on the corresponding side of the stub post. Also, orient the intermediate crosspieces so that the flange holes are in the top flange.

8. Attach remaining vertical posts (P1) to bottom chord by sliding between the channels and connecting with $\frac{3}{4}$- by 6-in hex bolts. Finger tighten nuts. *Note:* Orient posts so that the ends with two sets of $\frac{13}{16}$-in-diameter holes are at the bottom, the plugged ends are at the top, and the pilot holes are facing toward the deck.

9. Attach remaining crosspieces (C1) to the vertical posts (P1) using $\frac{3}{4}$- by 4-in hex bolts. Finger tighten nuts. *Note:* Point the bolt heads toward the nearest end of the bridge and orient such that the holes are all in the top flanges.

Adjust alignment horizontally and vertically. Make sure camber is set correctly.

10. Temporarily lay enough decking (D1 and D2) to provide a working platform for accessing the top chord. *Note:* Careful placement of the decking panels now will prevent the need to remove and reinstall them later. Orient end decking panels (D1) such that the holes that are $4\frac{11}{16}$ in from the end are directly over the end crosspieces. Place the center decking panel (D2) so that the holes near the center of the panel are aligned with the center intermediate crosspiece (C2). Temporarily attach the decking with a minimum of $4\frac{1}{4}$- by $2\frac{1}{2}$-in truss head machine screws. Finger tighten nuts.

Adjust alignment horizontally and vertically. Make sure camber is set correctly.

11. Lay out top chord girders (G1) in correct pairs on deck. Attach top chords by installing girder (G1) on both sides of vertical posts (P1, P1A, and P2) as follows:

A. Hang inside channel of top chord (G1) from one pin at each end vertical post (P2).

B. Attach inside channel of top chord to each end vertical post (P2) using a $\frac{3}{4}$- by 6-in hex bolt. Finger tighten nut. *Note:* Place bolt heads on inside face of channel.

C. Attach inside channel of top chord to center ertical posts (P1) using $2\frac{3}{4}$- by 6-in hex bolts each. Finger tighten nuts. *Note:* Place bolt heads on inside face of channel.

D. Remove nuts at each end of top chord and hang outside channel of top chord (G1) from one pin at each end vertical post (P2).

E. Attach outside channel of top chord to each end vertical post (P2) using a $\frac{3}{4}$- by 6-in hex bolt. Finger tighten nut. *Note:* Place bolt heads on inside face of channel.

F. Remove nuts at center vertical posts (P1) and attach outside channel of top chord to center vertical posts (P1) using $2\frac{3}{4}$" x 6" hex bolts each. Finger tighten nuts. *Note:* Place bolt heads on inside face of channel.

Verify that all holes in the top chord for the attachment of the diagonals are aligned properly before continuing to attach the top chord.

G. Continue attaching top chord by attaching to all vertical posts (P1, P2, and P3) using $2\frac{3}{4}$- by 6-in hex bolts per post. Finger tighten nuts.

12. Attach top chord spacers (S1) using $2\frac{1}{2}$- by 6-in hex bolts per spacer. Finger tighten nuts. *Note:* Plugged ends are at top of spacers.

Adjust alignment horizontally and vertically. Make sure camber is set correctly.

13. Attach tension diagonals (DT2) in center bay of span using $\frac{3}{4}$- by 6-in hex bolts as follows:

A. Attach bottom end of diagonals and finger tighten nuts. *Note:* Place bolt heads on the outside face of the outside channel.

B. Attach top end of diagonals by first inserting a drift pin into one hole in the top chord and working the second hole into alignment. Install the bolt into the second hole and remove drift pin. Install bolt into first hole. Finger tighten nuts. *Note*: Place bolt heads on inside face of the inside channel.

C. Attach diagonals to each other where they intersect using $\frac{3}{4}$- by $5\frac{1}{2}$-in hex bolt. Finger tighten nuts. *Note:* Place bolt heads on inside face of the inside channel.

14. Attach remaining tension diagonals (DT1) and all compression diagonals (DC1) using $\frac{3}{4}$- by 6-in hex bolts. Attach on tension diagonal (DT1) and one compression diagonal (DC1) in each bay progressing from the center of the bridge toward the ends in both directions in both trusses simultaneously. *Note:* Tension diagonals (DT1) are filled only at the ends and slope downward toward the center of the bridge when installed. They are attached on the outside of the compression diagonals. Compression diagonals (DC1) are filled from end to end and slope

upward toward the center of the span. Perform the work as follows:

A. Attach bottom end of diagonals and finger tighten nuts. *Note:* Place bolt heads on the outside face of the outside channel.

B. Attach top end of diagonals by first inserting a drift pin into one hole in the top chord and working the second hole into alignment. Install the bolt into the second hole and remove drift pin. Install bolt into first hole. Finger tighten nuts. *Note:* Place bolt heads on inside face of the inside channel.

C. Attach diagonals to each other where they intersect using $\frac{3}{4}$- by $5\frac{1}{2}$-in hex bolt. Finger tighten nuts. *Note:* Place bolt heads on inside face of the inside channel.

Proper alignment of the holes in the diagonals is dependent upon how carefully the span has been supported and assembled. It may be necessary to lift or lower the span slightly using wedges or jacks at different locations to properly align the holes. If necessary, a rat-tail file can be used to slightly enlarge the holes. Bolts can be driven with a mallet, but care must be taken to not splinter the FRP sections.

15. Attach outrigger plates (OP1) to each side of vertical posts (P1, P1A, and P2) using $\frac{1}{2}$- by $3\frac{3}{4}$-in hex bolts. Finger tighten nuts. *Note:* The long edge of the plate is on the bottom and points outward away from the deck.

16. Attach all outriggers (O1) to outrigger plates (OP1) and crosspieces (C1) using $\frac{1}{2}$- by $3\frac{3}{4}$-in hex bolts. Finger tighten nuts. *Note:* Place bolt heads toward nearest end of bridge.

Adjust alignment horizontally and vertically. Make sure camber is set correctly before tightening bolts. Also, verify that all bolts are in place and have a washer under each end and a lock washer and nut on the threaded end.

17. Tighten all bolts in bottom chord, horizontal bracing, and those that connect the crosspieces to the posts. Progress systematically from center toward ends of bridge. *Note:* Tighten all nuts until lock washers are compressed to a flat position. ***Do not over tighten.***

18. Tighten all bolts in outrigger plates and connections between outriggers and crosspieces. Progress systematically from one end of bridge to the other. *Note:* Transverse vertical alignment of posts and horizontal alignment of top chord must be correct before tightening outrigger connections. Tighten all nuts until lock washers are compressed to a flat position. ***Do not over tighten***.

19. Tighten all bolts in top chord and those at the intersections of the diagonals. Progress systematically from center toward end of bridge. *Note:* Tighten all nuts until lock washers are compressed to a flat position. ***Do not over tighten.***

20. Remove temporary supports as necessary to attach the remaining horizontal bracing (H2). *Note:* Tighten all nuts until lock washers are compressed to a flat position. ***Do not over tighten.***

21. Finish placing and attaching decking panels (D1 and D2) as needed. *Note:* Tighten all nuts until lock washers are compressed to a flat position. ***Do not over tighten.***

22. Verify that all bolts are properly tightened. Systematically progress from one end of bridge to the other. *Note:* All lock washers should be compressed to a flat position.

23. Remove all temporary supports.

24. Install midrails (M1 and M2) using No. 10–1-in ss pan head sheet metal screws. *Note:* Install midrail (M1) such that the end with the screw hole located 1 in from end of section is at the end of the bridge. Orient flanges to point inward toward the deck.

BRIDGE ASSEMBLY IS COMPLETE

Tools required:

1 Level (2 or 4 ft)
1 Carpenter's square
2 Open-end $1\frac{1}{8}$-in wrenches (for $\frac{3}{4}$-in nuts)
2 Open-end $\frac{3}{4}$-in wrenches (for ½-in nuts)
2 Ratchets equipped with $1\frac{1}{8}$- and $\frac{3}{4}$-in sockets
1 Small ratchet set
2 Drift pins
1 Rubber head hammer
2 Carpenter's hammers
1 Medium round (rat-tail) file
1 Crowbar
2 Phillips-head screwdrivers
1 Knife and 1 shear (for unpacking)
1 Tape measure
1 Battery-powered drill with Phillips-head bit and $\frac{1}{16}$- or $\frac{3}{32}$-in standard steel drill bit (optional)
1 String line
Miscellaneous material for shims (under bottom chord on top of each temporary support)

About the Authors

James "Scott" Groenier, professional engineer, began working for MTDC as a project leader in 2003. Scott earned a bachelor's degree in civil and environmental engineering from the University of Wisconsin at Madison and a master's degree in civil engineering from Montana State University. He worked for the Wisconsin and Illinois State Departments of Transportation and with an engineering consulting firm before joining the Forest Service in 1992. He worked as the east zone structural engineer for the Eastern Region and as a civil engineer for the Ashley and Tongass National Forests before coming to MTDC.

Merv Eriksson has a bachelor's degree in civil engineering from the University of North Dakota. He worked as a highway and bridge engineer with the U.S. Department of Transportation Federal Highway Administration before joining the Forest Service's Northern Region in 1979 as a structural engineer. Merv was the leader of the bridge design and construction group from 1986 until 1997. He joined MTDC where he served as the technical coordinator for the Wood in Transportation Program and managed a number of projects for the Technology and Development Program and the Forest Products Laboratory. Merv served as the regional bridge engineer for the Pacific Northwest Region before becoming the deputy director of engineering for the Intermountain Region in 2005.

Sharon Kosmalski worked for the Forest Service for 14 years in bridge design, construction, and inspection. She now lives in Willow, AK, where she works for the State of Alaska in water system design and approval. She has a degree in civil engineering from the University of Minnesota's Institute of Technology.

Library Card

Groenier, James Scott; Eriksson, Merv; Kosmalski, Sharon. 2006. A guide to fiber-reinforced polymer bridges. Tech. Rep. 0623–2824–MTDC. Missoula, MT: U.S. Department of Agriculture Forest Service, Missoula Technology and Development Center. 98 p.

Discusses the benefits and problems encountered with the use of lightweight, low-maintenance, easily constructed fiber-reinforced polymer (FRP) trail bridges in remote areas where the weight of conventional bridge-building materials such as steel, concrete, or timber make their use impractical. Beginning in 1997, the U.S. Department of Transportation Federal Highway Administration Recreational Trails Program and the USDA Forest Service Missoula Technology and Devel-opment Center funded the design, testing, and construction of two trail bridges made of FRP composite members. This report discusses the background of FRP composites, how they are manufactured, and the applicability of FRP products to trail bridges, along with their benefits and shortcomings. Case histories of five FRP bridges in national forests and discussions of their performance are included, as is information about the installation and testing of two FRP bridges, along with guidance on design, installation, maintenance, and inspection. The qualifications required for persons who design FRP bridges for the Forest Service are outlined. A list of current suppliers of FRP trail bridges is included.

Keywords: Case studies, composites, construction, damage, E.T. Techtonics, Inc., failures, Federal Highway Administration, fiberglass, inspections, maintenance, polymers, testing

---

Electronic copies of MTDC's documents are available on the Internet at: *http://www.fs.fed.us/eng/t-d.php* (Username: t-d, Password: t-d).

Forest Service and Bureau of Land Management employees can search a more complete collection of MTDC's documents, videos, and CDs on their internal computer networks at: *http://fsweb.mtdc.wo.fs.fed.us/search.*

For additional information about fiber-reinforced polymer bridges, contact Scott Groenier at MTDC.

Phone: 406–329–4719
Fax: 406–329–3719
E-mail: *jgroenier@fs.fed.us*