Episode 01: Can Carbon Fiber Save a Splitting Timber Bridge?

Two rural timber bridges over branches of Crow Creek near Toston, Montana | Video https://www.youtube.com/watch?v=Em-NaGK4CLM | 09:45

PART 1 COMPLETED LOAD-PATH TABLE

CALLOUT	COMPONENT	DOMINANT FORCE	WHY
[1]	**Loading head and spreader beam**	Compression	Pushes the test load down and splits it into two equal point loads.
[2]	**Girder top fibers, midspan**	Compression	Top of the girder shortens in the constant-moment zone between load points.
[3]	**GFRP channel, shear span**	Shear/Friction	Fastened U-section resists sliding along splits between support and load point.
[4]	**Hybrid FRP strip, bottom face**	Tension	Carbon-glass strip carries tension across the crack on the stretched bottom face.
[5]	**Load plate at load point**	Bearing	Spreads point load over the wood so fibers do not crush locally.
[6]	**Support bearing plate**	Bearing	Transfers the girder reaction into the support without crushing the beam end.
[7]	**String potentiometer, midspan**	No load (instrument)	Cable sensor records midspan deflection; it carries no structural load.
[8]	**Extensometer on beam side**	No load (instrument)	Clip-on gauge reads local deformation over a short length; no structural load.

Accept any force type the callout actually carries, provided the student justifies it from the load path. An instrument is marked as carrying no load: it measures the structure, it does not resist it.

PART 3 WORKED SOLUTIONS, PROBLEMS 1 TO 2

Problem 1. The salvaged test girders (main beams supporting the deck) were 6 in x 18 in and 8 in x 18 in. Using 1 in = 25.4 mm, find each cross-sectional area. Peak shear stress (sliding stress between internal wood layers) in a rectangular beam is proportional to V/A. Under the same shear force V, what is the ratio of peak shear stress in the 8 in beam to the 6 in beam?

1. Convert with 1 in = 25.4 mm: b6 = 6 in x 25.4 mm/in = 152.4 mm, b8 = 8 in x 25.4 mm/in = 203.2 mm, and h = 18 in x 25.4 mm/in = 457.2 mm.
2. A6 = b x h = 6 in x 18 in = 108 in^2; applying $(25.4\ mm/in)^2 = 645.16\ mm^2/in^2$ gives 108 in^2 x 645.16 mm^2/in^2 = 69,677 mm^2, matching 152.4 mm x 457.2 mm.
3. A8 = 8 in x 18 in = 144 in^2; applying 645.16 mm^2/in^2 gives 144 in^2 x 645.16 mm^2/in^2 = 92,903 mm^2, matching 203.2 mm x 457.2 mm.
4. At equal V, $\tau 8 / \tau 6$ = A6 / A8 = 108 in^2 / 144 in^2 = 0.750, and in SI 69,677 mm^2 / 92,903 mm^2 = 0.750, so the 8 in (203.2 mm) girder sees 25.0 percent less peak shear stress.

Problem 2. For the same 6 in x 18 in and 8 in x 18 in girders, use 1 in = 25.4 mm and 1 kip-ft = 1.3558 kN-m. Compute each section modulus (shape's resistance to bending stress) for a rectangle. If bending stress (stretch or squeeze stress from bending) limits both controls equally, how much more moment can the 8 in control carry than the 6 in control?

1. Convert with 1 in = 25.4 mm: 6 in x 25.4 mm/in = 152.4 mm, 8 in x 25.4 mm/in = 203.2 mm, and 18 in x 25.4 mm/in = 457.2 mm.
2. $S6 = b\ h^2 / 6$ = 6 in x $(18\ in)^2 / 6$ = 324 in^3; applying $(25.4\ mm/in)^3 = 16{,}387\ mm^3/in^3$ gives 324 in^3 x 16,387 mm^3/in^3 = 5.309 x 10^6 mm^3, matching 152.4 mm x $(457.2\ mm)^2 / 6$.
3. S8 = 8 in x $(18\ in)^2 / 6$ = 432 in^3; applying 16,387 mm^3/in^3 gives 432 in^3 x 16,387 mm^3/in^3 = 7.079 x 10^6 mm^3, matching 203.2 mm x $(457.2\ mm)^2 / 6$.
4. At equal limiting stress $\sigma = M / S$, M8 / M6 = S8 / S6 = 432 in^3 / 324 in^3 = 1.333, and in SI 7.079 x 10^6 mm^3 / 5.309 x 10^6 mm^3 = 1.333.
5. So M8 = 1.333 M6 in kip-ft; multiplying both moments by 1.3558 kN-m per kip-ft gives M8 = 1.333 M6 in kN-m, a 33.3 percent larger moment for the 8 in (203.2 mm) control.

Episode 01: Can Carbon Fiber Save a Splitting Timber Bridge?

Two rural timber bridges over branches of Crow Creek near Toston, Montana | Video https://www.youtube.com/watch?v=Em-NaGK4CLM | 09:45

PART 3 WORKED SOLUTIONS, PROBLEMS 3 TO 5

Problem 3. A split (lengthwise crack running along the grain) repair using full-length GFRP channels (glass-fiber U-sections fastened along the girder) restored 6 in x 18 in beams to 97.1 percent of control moment capacity (largest bending moment before failure) and brought 8 in x 18 in beams to 112.2 percent. Each control has factor of safety (capacity divided by the applied demand) FS_c. Using 1 in = 25.4 mm and 1 kip-ft = 1.3558 kN-m, find each repaired factor of safety and the repaired 8 in to 6 in capacity ratio.

1. Capacity ratio r = M_repaired / M_control: r6 = 0.971 and r8 = 1.122; converting both moments by 1.3558 kN-m per kip-ft leaves r6 = 0.971 and r8 = 1.122 in kN-m as well.
2. FS_r = capacity / demand = r x FS_c with demand unchanged: FS_r6 = 0.971 FS_c and FS_r8 = 1.122 FS_c, whether demand and capacity are both in kip-ft or both in kN-m.
3. Margin check: FS_r6 of at least 1.000 requires FS_c of at least 1 / 0.971 = 1.030 in kip-ft or kN-m terms, while the 8 in repair raises margin by 1.122 - 1.000 = 0.122, or 12.2 percent.
4. Control moment ratio from section shape: 8 in x 25.4 mm/in = 203.2 mm and 6 in x 25.4 mm/in = 152.4 mm at equal 18 in (457.2 mm) depth, so M_c8 / M_c6 = 8 in / 6 in = 1.333 and 203.2 mm / 152.4 mm = 1.333.
5. Repaired capacity ratio = 1.333 x (1.122 / 0.971) = 1.333 x 1.156 = 1.541, so the repaired 8 in (203.2 mm) girder carries about 1.541 times the moment of the repaired 6 in (152.4 mm) girder in kip-ft or kN-m.

Problem 4. Channel strengthening raised shear capacity (largest shear force before the beam fails) by 23.1 percent for undamaged 6 in x 18 in girders and 48.5 percent for 8 in x 18 in girders. Assume each control's shear capacity scales with cross-sectional area. Using 1 in = 25.4 mm and 1 kip = 4.448 kN, find the share of strengthened capacity carried by the GFRP channels (glass-fiber U-sections fastened along the girder) and the strengthened 8 in to 6 in capacity ratio.

1. Strengthened capacity V_s = (1 + gain) x V_c: V_s6 = 1.231 V_c6 and V_s8 = 1.485 V_c8 in kip; multiplying both sides by 4.448 kN/kip gives the same 1.231 and 1.485 factors in kN.
2. Channel share = gain / (1 + gain): 0.231 / 1.231 = 0.188 (18.8 percent) for the 6 in girder and 0.485 / 1.485 = 0.327 (32.7 percent) for the 8 in girder, identical in kip and in kN after the 4.448 kN/kip factor.
3. Control ratio from area: A8 = 8 in x 18 in = 144 in^2 and A6 = 6 in x 18 in = 108 in^2; applying 645.16 mm^2/in^2 gives 92,903 mm^2 and 69,677 mm^2, so V_c8 / V_c6 = 144 / 108 = 1.333 and 92,903 / 69,677 = 1.333.
4. Strengthened ratio V_s8 / V_s6 = 1.333 x 1.485 / 1.231 = 1.608 in kip or kN, so the strengthened 8 in (8 in x 25.4 mm/in = 203.2 mm) girder carries about 1.608 times the shear of the strengthened 6 in (152.4 mm) girder.

Problem 5. Strip-only (bonded strips without a channel) strengthening raised 8 in x 18 in moment capacity (largest bending moment before failure) by 140.0 percent, but its control underperformed; C-S (channels and strips used together) strengthening gave 45.0 percent. Field installs took 1.5 hours and 30 minutes, and inspection covered seven months on girders more than 80 years old. Using 1 kip-ft = 1.3558 kN-m, 1 hour = 60 minutes, 1 minute = 60 seconds, and 1 year = 12 months, decide which gain to design on and what to monitor next.

1. Capacity factor = 1 + gain: strip-only 1 + 1.400 = 2.400 M_c and C-S 1 + 0.450 = 1.450 M_c in kip-ft; multiplying by 1.3558 kN-m per kip-ft keeps 2.400 M_c and 1.450 M_c in kN-m, and 2.400 rests on a weak control.
2. Install time: 1.5 h x 60 min/h = 90 min, then 90 min x 60 s/min = 5,400 s, versus 30 min x 60 s/min = 1,800 s; ratio 90 min / 30 min = 5,400 s / 1,800 s = 3.0 for the broken-girder C-S job.
3. Evidence window: 80 years x 12 months/year = 960 months, so 7 months / 960 months = 0.0073 (0.73 percent) of girder age and less than one 12-month seasonal cycle.
4. Decision: design on the 1.450 C-S factor in kip-ft or kN-m for broken or severely cracked girders, use strip-only for minor cracks, and monitor deflection, bond lines, fasteners, moisture, and fatigue (weakening from many repeated load cycles) for several seasons.

Episode 01: Can Carbon Fiber Save a Splitting Timber Bridge?

Two rural timber bridges over branches of Crow Creek near Toston, Montana | Video https://www.youtube.com/watch?v=Em-NaGK4CLM | 09:45

WATCH FOR COMMON MISCONCEPTIONS

1. **Misconception: A split or cracked timber girder must be replaced or sistered with heavy steel.** Lightweight FRP split repair restored 97.1 percent of control flexure capacity in 6x18 girders and 112.2 percent in 8x18 girders.
2. **Misconception: The repair with the biggest percentage gain is always the best choice.** The 140.0 percent strip-only gain was inflated by a weak control; repair choice must match damage severity, not headline numbers.
3. **Misconception: Code calculations predict exactly what a timber girder will hold.** Calculated moment capacities were consistently below measured values; every tested beam exceeded its calculation, so the method is conservative.
4. **Misconception: Strips and channels do the same job on a girder.** Bottom-face strips carry tension and raise moment capacity, while fastened channels resist shear and sliding along splits.
5. **Misconception: Repairing a bridge girder means closing the road for days.** Field installs with standard tools took about 1.5 hours on the broken girder and 30 minutes on the minor crack.
6. **Misconception: Seven months with no visible deterioration proves the repair will last decades.** A seven-month visual check on two bridges cannot establish fatigue, weathering, or long-term bond durability.

RUBRIC 20 POINT GRADING SCALE

TASK	CRITERION	POINTS
Pause checkpoint responses	All four answers use correct force vocabulary and cite episode evidence.	4
Diagram force mapping	Each of the 8 badges is matched to its component and dominant force.	2
Problems 1-2 calculations	Areas, section moduli, and ratios correct, with conversion factors shown and US and SI in every step.	4
Problems 3-4 engineering analysis	Factor of safety, capacity ratios, and channel load share computed with both unit systems and interpreted correctly.	6
Problem 5 trade-off reasoning	Rejects the inflated gain, matches repair to damage, and names a justified monitoring plan.	4
Total	Full credit requires correct units on every numeric answer	**20**

Deduct one point, not the whole item, for a missing unit. Deduct two for a ratio inverted, because the error hides a real misunderstanding of demand against resistance rather than a slip in arithmetic.

GRADING NOTES WHAT FULL CREDIT LOOKS LIKE

- **Load path.** The student names each numbered part and gives one dominant force, then explains how the load transfers from one numbered component to the next, as the diagram draws it.
- **Units.** Every numeric answer carries the US customary and SI result, with the conversion shown, not just the final number.
- **Assumptions.** The student separates demand from resistance before assigning a cause to a changing factor of safety, and treats a measured reserve as reserve rather than as capacity already spent.
- **Monitoring.** The design trade-off answer names the measurement that would trigger action and the location where that measurement is most sensitive.