MILE POINT INDEX // RESEARCH HIGHLIGHT BULLETIN

Can Carbon Fiber Save a Splitting Timber Bridge?

Two rural timber bridges over branches of Crow Creek near Toston, Montana

The Challenge. Broadwater County grew from 5,612 residents in 2010 to 6,774 in 2020, and peak traffic on S285 near Toston reaches 4,902 vehicles a day. Of four bridges within five miles, one is Poor and three are Fair, all fifty years old or more. A split girder means weight limits, closure, or emergency replacement. The study tested whether allowable-stress equations, plus a perfect-bond assumption for the retrofit, predict capacity.

The Research. The team salvaged twenty-two Douglas-fir and larch girders, six by eighteen and eight by eighteen inches, some split, some cracked, some sound. Coupons of the glass channels and carbon-glass strips were pulled to failure first. Beams were then tested in four-point bending, set up for shear and for flexure, with string potentiometers, a load cell, an extensometer, bearing plates, lateral bracing, and calipers.

Key Findings. The verdict was conservative: every beam carried more than its calculated capacity. Glass channels added 11.3% and 23.1% shear on narrow beams, 11.5% and 48.5% on wide. Carbon-glass crack repair raised moment capacity 29.9% and 50.5%. A six-foot channel restored narrow split beams to 97.1% of control and wide beams reached 112.2%. Installation took 1.5 hours and 30 minutes; seven months later, nothing showed.

Engineering Impact. Designers should match the repair to the damage: carbon-glass for broken or badly cracked girders, strips alone for minor cracks. Treat allowable-stress predictions as conservative, not exact. Specifications need surface preparation, strip end anchorage, confinement, and cure time for cold mornings. Inspectors should tap the channels, check strip ends for moisture, and keep monitoring, since fatigue, freeze-thaw, and long-term durability remain unproven.



Timber bridge



Frp install



Frp strip

REPORT DOI
milepointindex.com/

CASE FILE
milepointindex.com/2026-11-07_sr-285-bridge/

Scan to open the published primary research report and full Mile Point Index Case File. The bulletin condenses the verified research brief; the four classroom handouts behind it carry the load path, the data table, five worked problems, and the grading rubric.

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

01 STANDARDS AND COURSE ALIGNMENT

STANDARD OR COURSE	ALIGNMENT
NGSS HS-PS2-6	Explain how carbon-glass strip fibers carry tension across cracked timber girders, citing measured C-S crack repair moment gains of 29.9-50.5 percent.
NGSS HS-ETS1-3	Weigh GFRP channel and carbon-glass strip repair against steel sister girders using measured capacity gains, 30-90 minute installs, and a seven-month inspection.
AP Physics 1	Apply static equilibrium to four-point bending of timber girders, separating midspan bending moment from support shear resisted by GFRP channels.
University civil engineering	Compare allowable-stress and perfect-bond predictions of timber girder bending and shear capacity with measured capacities, which exceeded calculation in every test.

One 50 minute period. The episode runs 09:45; the remaining time is discussion, worksheet, and debrief. No prior knowledge of the report's discipline is assumed: every term the class needs is glossed in the vocabulary table on page two, and every number used in class appears on the student worksheet.

02 BELL TO BELL PACING GUIDE

CLOCK	ACTIVITY	WHAT HAPPENS
0–5 min	**Hook and force map**	Show a split timber girder. Students sketch where compression, tension, shear, and bearing act under a truck.
5–23 min	**Video with four pauses**	Screen 01:44-02:45. Pause at 06:15, 08:04, 05:20, and 08:18 for prediction, test evidence, repair choice, and limits.
23–40 min	**Diagram and Problems 1-3**	Trace badges 1-8 on the diagram, then solve Problems 1-3 in pairs, carrying US and SI units in every step.
40–50 min	**Problems 4-5 and exit check**	Teams finish load share and the trade-off problem, then defend one damage-matched repair and one monitoring item.

FOUR PAUSE AND DISCUSS CHECKPOINTS

Build the pause list on the board before the bell. Each one is a two minute stop; skipping them turns a field investigation into a video.

PAUSE	SEQUENCE	ASK THE CLASS	LISTEN FOR
01:44	**Part 1: The everyday question**	How could fiber-reinforced polymer (strong fibers held in hardened resin) help a cracked girder (main beam supporting the deck) carry traffic?	The fibers resist tension, and a channel (U-shaped reinforcement around the girder) resists shear; tests must verify the gain.
02:45	**Part 2: The field test**	In four-point bending (two loads create a central bending region), why track deflection (movement of the beam under load) instead of failure load alone?	Deflection shows damage growth before failure, while a load cell (sensor that measures applied force) links that growth to force.
06:15	**Part 3: Where it's happening on the ground**	Match C-S (channels and strips used together) and strip-only (bonded strips without a channel) to a broken girder and a minor crack.	Use C-S on the broken girder and strip-only on the minor crack, matching each retrofit to damage severity.
08:04	**Part 4: What comes next**	Calculated moment capacity (largest bending moment before failure) was below every measured value. Is a safe-side prediction enough for widespread use?	No. Few specimens, two bridges, and a seven-month visual check leave fatigue, fastener, and durability questions open.

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03 KEY VOCABULARY AND UNITS REFERENCE

TERM	WORKING DEFINITION	US CUSTOMARY	SI
Shear capacity	Largest shear force a girder resists before its fibers slide apart along the grain.	kip	kN
Moment capacity	Largest bending moment a girder resists before cracking or crushing ends its strength.	kip–ft	kN–m
Allowable stress	Design stress limit after reductions for wet service, load duration, member size, and stability.	psi	kPa
Section modulus	Section property linking bending moment to peak bending stress; larger values mean lower stress.	in^3	mm^3
Composite action	Timber and FRP strain together under perfect bond so both share internal force.	dimensionless	dimensionless
GFRP channel	Pultruded glass-fiber U-section fastened along a girder to resist shear and close splits.	in	mm
String potentiometer	Cable-reel sensor that converts beam deflection into an electrical displacement reading.	in	mm
Capacity factor	Measured capacity divided by a control or calculated capacity; above one means a gain.	dimensionless	dimensionless

Conversion factors for the board: 1 kip = 4.448 kN. 1 psf = 0.04788 kPa. 1 in. = 25.4 mm. 1 ft = 0.3048 m. Pressure and stress share units because stress is force per unit area.

BEFORE THE BELL

- Print one worksheet per student, double sided.
- Set the pause points at 01:44, 02:45, 06:15, 08:04.
- Sketch the unlabelled section on the board before pressing play.

TEACHING MOVES THAT WORK HERE

- Anchor every number to the physical load path in the diagram.
- Require units at every step in both the US and SI systems.
- Close on the design trade-off, not on the arithmetic.

04 ASSESSMENT MAP

The full 20 point rubric, with one criterion per task, is printed in the Answer Key and Grading Rubric handout. Grade the numbered load-path table and the five problems; a correct number with no units earns half credit.

Suggested weighting: the diagram table and the five problems carry the grade. A student who can draw the load path and compute both ratios has met the standard even if one arithmetic step slips.

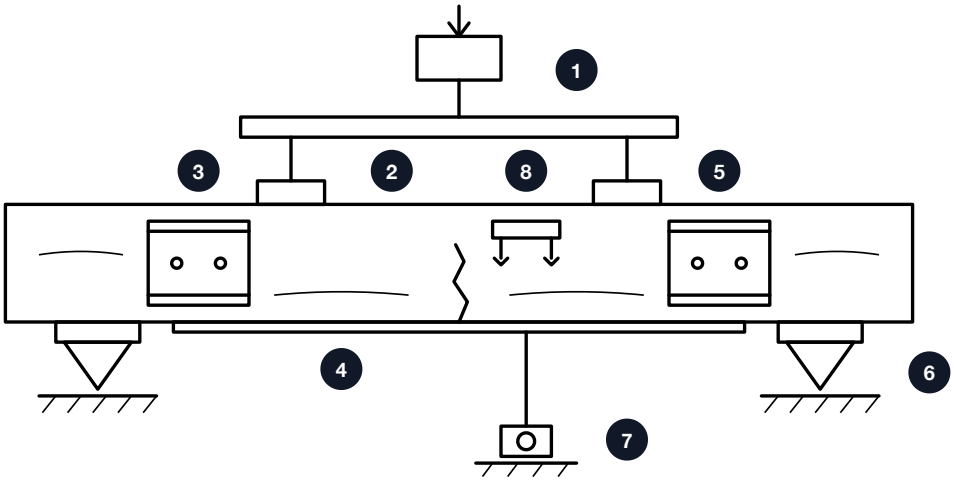
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Name: Date: Class / Period:

PART 1 LOAD PATH CROSS-SECTION

Eight parts are numbered. Name each one, then circle the force it carries most of. Two parts only measure.



CALLOUT COMPONENT NAME	DOMINANT FORCE				
[1]	☐ Compression	☐ Tension	☐ Shear / friction	☐ Bearing	☐ None
[2]	☐ Compression	☐ Tension	☐ Shear / friction	☐ Bearing	☐ None
[3]	☐ Compression	☐ Tension	☐ Shear / friction	☐ Bearing	☐ None
[4]	☐ Compression	☐ Tension	☐ Shear / friction	☐ Bearing	☐ None
[5]	☐ Compression	☐ Tension	☐ Shear / friction	☐ Bearing	☐ None
[6]	☐ Compression	☐ Tension	☐ Shear / friction	☐ Bearing	☐ None
[7]	☐ Compression	☐ Tension	☐ Shear / friction	☐ Bearing	☐ None
[8]	☐ Compression	☐ Tension	☐ Shear / friction	☐ Bearing	☐ None

PART 2 INSTRUMENTED FIELD TELEMETRY

Left is the design assumption. Middle is what the field instruments measured. The gap is the story.

PARAMETER	DESIGN ASSUMPTION	MEASURED IN FIELD
Shear gain, strengthened 6x18 beam	Control shear capacity, 100%	+23.1% with GFRP channels
Shear gain, strengthened 8x18 beam	Control shear capacity, 100%	+48.5% with GFRP channels
Moment gain, C-S crack repair 8x18	Control moment capacity, 100%	+50.5% after C-S repair
Strip-only strengthening, 8x18 moment	Control moment capacity, 100%	+140.0% over controls
Split repair flexure, 6x18 beam	Restore full control capacity	97.1% of control capacity
Calculated versus measured moment capacity	Allowable-stress, perfect-bond prediction	Every tested beam exceeded calculation
Field installation time, two bridges	Heavy sister-girder repair, long closure	1.5 hours and 30 minutes
Seven-month follow-up inspection result	Long-term durability assumed	No visible deterioration or issues

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PART 3 APPLIED PROBLEMS

Show the unit conversion and the formula you used. A correct number with no work is worth half credit.

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?

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?

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.

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.

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.

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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.

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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.

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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.