

Shake Table Bridge Challenge: Define, Build, Shake, Improve

Investigation question: How can a craft-stick bridge be designed to carry its load through three measured levels of shaking, meeting the performance targets its importance demands, within a materials budget?

Engineering design challenge

Groups of 4

2 sessions

Setup 10 · Activity 90 · Cleanup 10 min

MS-ETS1-1 · practice

MS-ETS1-2 · practice

MS-ESS3-2 · practice

Scientific purpose

Each group draws a bridge type (ordinary, important or lifeline), turns that type's performance targets into precise, measurable criteria and constraints, and builds a craft-stick bridge across a 25 cm gap on a hand-driven shake table. The table is 'measured': every shaking level has a fixed stroke distance, beat rate and duration, checked by counting strokes before testing, so different designs meet the same shaking. Groups test at three levels, pool results in a class table, identify the features shared by the best performers, redesign one feature and retest. The lab carries out the lesson's engineering spread: precise criteria, importance matched to hazard level, and a systematic comparison of designs.

Why this helps students with this chapter

Students usually build 'the strongest bridge possible'. Assigning a bridge type with its own targets and budget makes them face the real engineering question from the lesson: how good does this structure need to be, given how important it is and how often each level of shaking happens? Writing measurable criteria before building gives the test meaning, and the measured shaker makes the comparison fair enough that the class can argue from data about which features work.

Standards connections

MS-ETS1-1 (practice, turning performance targets into precise, measurable criteria and listing constraints before building): The design brief requires every criterion to be measurable (load stays on the deck, sag change in millimeters, joints intact, rating at each shaking level) and every constraint to be stated (budget, materials, time, no supports in the river). The problem frame and the targets are supplied, so students practice rather than fully define the problem.

MS-ETS1-2 (practice, comparing tested designs systematically against the criteria): The class results table puts every design's cost, features and ratings side by side so groups can judge which designs best meet the criteria and constraints and justify a redesign from that comparison.

MS-ESS3-2 (practice, the mitigation half: testing a technology meant to reduce earthquake damage): Earthquake-resistant structures are one of the mitigation technologies the PE refers to. The shaking levels stand for frequent, rare and very rare earthquakes, but students analyze test data from a model rather than data on real hazards, so this is practice.

Roles (rotate each session)

- **Lead builder:** Leads construction from the group's sketch and keeps the bridge within the design rules.
- **Shaker:** Practices the three shaking levels until the stroke count matches the target, then shakes the group's bridge (and checks one other group's calibration).
- **Measurer:** Measures mid-span sag with the ruler before and after each level, counts loosened or broken joints, and decides the rating with the recorder.
- **Budget keeper and recorder:** Tracks every material used and its cost, fills the test tables, and reports the group's results to the class table.

Materials

Item	Quantity	Per	Note
Rimmed baking sheet or plastic cafeteria tray, about 30 x 45 cm (the shake-table base)	1	group	
Stiff corrugated cardboard or foam board, about 25 x 35 cm (the moving platform)	1	group	
Round pencils or 1 cm wooden dowels about 18 cm long (rollers under the platform)	6	group	
Latex-free rubber bands and medium binder clips to keep the platform centered	2 bands, 4 clips	group	
Two sturdy small boxes or wooden blocks 8 to 10 cm tall (the river banks)	2	group	
Craft sticks (standard size, about 11.5 cm)	40	group	
Masking tape, torn or cut into 10 cm pieces as needed	1 roll per 2 groups	class	
Paper clips, latex-free rubber bands for building, string, index cards	10 clips, 6 bands, 1 m string, 4 cards	group	
Load: 40 pennies in a zip-top sandwich bag (about 100 g)	1 bag	group	Check each bag on a kitchen scale and adjust to 100 g plus or minus 2 g; older pennies are heavier.
30 cm ruler with millimeter marks	1	group	

Phone or tablet with a free metronome app (or one projected class metronome)	1	group	
Scissors	1	group	
Safety goggles	1	student	

Estimated cost: about 35 to 60 to set up 8 groups (the low end with borrowed trays), then about 10 to 15 per class (estimates) (an estimate; Estimated U.S. discount-store prices: trays about 3 dollars each (or borrowed from the cafeteria), 1,000 craft sticks about 10 dollars, 4 rolls of masking tape about 8 dollars, latex-free rubber bands about 4 dollars, binder clips about 5 dollars, paper clips, string and index cards about 6 dollars, 320 pennies about 3 dollars (reusable). Cardboard, boxes, pencils, rulers and goggles are classroom stock. Sticks and tape are the per-class consumables.)

Safety

- Wear goggles while shaking and whenever rubber bands are stretched: a band can snap and a stick can flip up during shaking.
- Pinch point: keep fingers off the tray rim and away from the gap between the moving platform and the rim. The shaker holds the platform by its sides only and reverses at the tape mark instead of slamming into the rim.
- Rollers must stay inside the tray. Pick up any pencil, penny or paper clip that falls to the floor at once; round objects underfoot are a slip hazard.
- Broken craft sticks splinter. Break or cut sticks pointing down at the table, never toward a face, and put broken pieces in the trash.
- Cut away from your body with scissors. Use latex-free rubber bands in case anyone has a latex allergy. Wash hands after handling the pennies.
- No hot glue or other heated tools: glue guns run well above 50 degrees C. Tape, clips, string and bands are the only fasteners.

Teacher preparation and setup

1. Build one shake table: lay the six rollers parallel across the tray, set the platform on them, and clip one rubber band from each short end of the platform to the tray rim so the platform returns to center. Put masking-tape marks on the tray rim at 1, 2 and 3 cm on each side of the platform's center line.
2. Try the three shaking levels yourself with an empty platform and a metronome, and count strokes for 10 seconds. A stroke is one move from one side mark to the other. Targets: Level 1 is 20 strokes in 10 seconds, Level 2 about 27, Level 3 about 33.
3. Prepare importance cards in equal numbers: Ordinary (budget 40 units), Important (55 units) and Lifeline (70 units), each printed with its targets from the performance table.
4. Fill and check the penny bags; pre-cut a supply of 10 cm tape pieces to make budgeting easy.
5. Tape the two bank boxes to each platform 25 cm apart (inside edges) before class, or have students do it as the first step, so every group has the same gap.

Investigation design

Independent variable	The bridge design (structure, bracing, connections and materials), changed once between version 1 and version 2.
Dependent variable	The performance rating after each shaking level, judged from whether the load stays on the deck, the change in mid-span sag (mm) and the number of loosened or broken joints.
Controlled	Gap between banks (25 cm) and bank height; Load (100 g bag) placed at mid-span; Stroke distance, beat rate and duration for each level, checked by stroke counts; The same shaker and shake table for both versions; Same rating rules and order of levels (1, then 2, then 3, no repairs)
Trials	One full test sequence per version; the class table provides about eight designs for comparison, and version 2 is compared with version 1 of the same group.
Comparison	Each version is compared with the group's own criteria and with the other designs in the class table.

Student procedure

1. Session 1. Draw an importance card. Read the performance targets for your bridge type and the design rules. Complete the design brief: write each criterion as a precise, measurable statement and say how you will check it, then list the constraints. Answer q1 and q2.
2. Calibrate the shaker: with an empty platform, the shaker practices each level with the metronome while the recorder counts strokes for 10 seconds. Repeat until the count is within 2 of the target (20, 27, 33). Record both counts.
3. Sketch version 1 and label the materials, joints and how the load's weight is carried to the banks. Estimate the cost; it must not exceed your budget.
4. Build version 1 (25 minutes). The bridge must span the 25 cm gap, have a deck at least 6 cm wide, rest on the banks with nothing touching the platform between them, and be attached only with budgeted tape, clips, string or bands. Record the actual materials and cost.
5. Session 2. Test version 1. Measure the deck height at mid-span with no load, then place the penny bag at mid-span and measure again (sag = unloaded height minus loaded height). Shake at Level 1, inspect, measure and rate; then Level 2; then Level 3. Do not repair between levels. Use the rating scale exactly as written.
6. Report your bridge type, cost, main design features and three ratings to the class table. Study the table and answer q3: which features do the best-performing bridges share?
7. Redesign: change one main feature (answer q4 first, including your prediction), staying within budget. Build version 2 and test it with the same shaker, the same load position and the same levels.
8. Answer the analysis questions individually. Return pennies, rollers and boxes; recycle unbroken sticks.

Expected observations

- These are expected outcomes, not results from a tested run: flat plank decks of taped sticks usually pass Level 1, but the penny bag often slides off at Level 2 unless the deck has a curb or rail.

- Tall, narrow structures and side walls made of rectangles tend to sway and fold at Level 2 or 3; triangulated side walls and cross-bracing usually survive to Level 3 with minor damage.
- Tape joints are the usual first failure: tape peels or slips before sticks break, so wrapped or doubled joints perform better.
- Bridges attached rigidly to the banks may crack at the ends, while bridges that can shift slightly on the banks (or rest on rubber-band pads) sometimes ride out the shaking better, if they cannot slide off.
- Higher budgets do not guarantee higher ratings; the class table usually shows a well-braced ordinary bridge outperforming a heavily built lifeline bridge.

Likely difficulties

- Inconsistent shaking between groups. Insist on the calibration counts, and if time allows, have one trained shaker per station shake every bridge at that station.
- Slamming the platform into the rim at the end of each stroke adds jolts that are not part of the protocol. Coach the shaker to reverse at the tape mark.
- Measuring sag at different points. Mark mid-span on the deck with a pencil and always stand the ruler at that mark on the platform.
- Going over budget during the build. The budget keeper should approve every new piece of material before it is used.
- Rating disagreements. Read the rating scale aloud and decide by the written rules, not by how the bridge looks.

Structured debrief

1. Display the class comparison table and sort it by Level 3 rating. Ask which features the top bridges share. Typical answers: triangles in the side walls, diagonal cross-bracing under or across the deck, a low, wide structure, a curb that keeps the load from sliding, and joints wrapped so tape cannot peel. Ask for the physics: a triangle cannot change shape without a side changing length, so triangulated frames resist the sideways sway that folds a rectangle.
2. Compare bridge types. Did lifeline teams with 70 units always beat ordinary teams with 40? Usually not: where bracing goes matters more than how much material is used. Connect to the lesson: engineers match performance to importance, and money spent well beats money spent everywhere.
3. Discuss the measured shaker. Did everyone's Level 2 feel the same? The stroke counts were the evidence that it did, roughly. Point out what the model cannot do: real shaking comes in many frequencies and directions at once, including up and down, real bridges are far larger and sway much more slowly, and the two ends of a long real bridge can move differently.
4. Close on mitigation: the shake table stands in for the tests engineers run on large shake tables and computer models before building. Japan's base isolators and the Bay Bridge's energy-absorbing parts are ideas students may have stumbled on with rubber bands and flexible joints.

Recording sheet: what students fill in

Lab 2 recording sheet: Shake Table Bridge Challenge

Your county needs a new bridge in earthquake country. How well the bridge must survive shaking depends on how important it is. Your group has drawn one bridge type. Your job is to write precise criteria, build a bridge that meets them within your budget, test it with **measured** shaking, and improve it using the class's evidence.

Measured shaking levels — A **stroke** is one move of the platform from one side mark to the other.

Level 1 (frequent, moderate): marks 1 cm each side of center, one stroke per beat at 120 beats per minute, for 10 seconds (20 strokes). **Level 2 (rare, strong):** marks 2 cm each side, 160 beats per minute, 15 seconds (40 strokes). **Level 3 (very rare, strongest):** marks 3 cm each side, 200 beats per minute, 15 seconds (50 strokes). Before testing, count strokes for 10 seconds; you must be within 2 of 20, 27 or 33.

Rating scale (decide after each level) — **No damage:** load on the deck, no joint loosened, sag increased by 2 mm or less. **Minor damage, stays open:** load on the deck, at most 2 joints loosened and none broken, sag increased by 5 mm or less. **Damaged, emergency use only:** load on the deck and the deck still spans the gap, but more damage than that. **Closed, still standing:** the load fell off or the deck tilted badly, but the bridge still spans the gap without touching the platform. **Collapsed:** any part of the deck touches the platform between the banks, or the bridge falls off a bank.

Performance targets by bridge type (meet the target or do better)

Bridge type and budget	After Level 1	After Level 2	After Level 3
Ordinary (farm road), 40 units	Minor damage, stays open	Closed, still standing	Closed, still standing
Important (main road), 55 units	No damage	Damaged, emergency use only	Closed, still standing
Lifeline (only hospital route), 70 units	No damage	Minor damage, stays open	Damaged, emergency use only

Material prices

Material	Cost in units
1 craft stick	1
10 cm of masking tape	1
1 paper clip	1
1 rubber band	2
10 cm of string	1
1 index card	2

Design rules: span the 25 cm gap and rest on top of both banks; deck at least 6 cm wide; nothing may touch the platform between the banks (it is the river); only the listed materials, no glue; 25 minutes to build each version; every piece of material counts toward the budget, including tape used to attach the bridge to the banks.

Our design brief (write precise, measurable statements)

Item	Our precise statement	How we will measure or check it
Bridge type and budget		
Criterion after Level 1		
Criterion after Level 2		
Criterion after Level 3		
Load and span criteria		
Constraint: budget		
Constraint: materials and rules		
Constraint: time		

1. A classmate's brief says, 'Our bridge should be strong and not break.' Rewrite this as two precise criteria for your bridge type that someone else could check with a ruler and the rating scale.

Answer: Example for an important bridge: (1) After Level 1 the 100 g load is still at mid-span, no joint is loosened and the sag has increased by 2 mm or less. (2) After Level 3 the bridge still spans the 25 cm gap with no part of the deck touching the platform. Lifeline example: after Level 2 the load is still on the deck, at most 2 joints are loosened and none broken, and sag has increased by 5 mm or less.

Why: 'Strong' and 'not break' cannot be checked. Precise criteria name a level of shaking and a measurable outcome taken from the rating scale and the group's target.

- Two criteria, each tied to a specific shaking level
- Each uses a measurable outcome (load position, millimeters of sag, number of joints, spanning the gap)
- Matches the group's bridge-type targets

2. Which of your criteria or constraints comes from the science of earthquakes (how strong or how frequent shaking is), and which comes from people's needs or limits? Give one of each.

Answer: From the science of earthquakes: the three shaking levels and the rule that stronger shaking is tested less leniently are based on how strong and how frequent earthquakes are (for example, 'no damage after Level 1' reflects frequent moderate shaking). From people's needs or limits: the budget, the 25-minute build time, the no-supports-in-the-river rule (boats or floods), and the higher target for a hospital route because people depend on it after an earthquake.

Why: MS-ETS1-1 asks for criteria and constraints that account for scientific principles and impacts on people; this question makes students separate the two sources.

- One item correctly linked to earthquake strength or frequency
- One item correctly linked to people's needs or resource limits

-  Sketch version 1 from the side and from above. Label the materials, every joint, the banks, and arrows showing how the weight of the load travels to the banks.

Answer: A side view and a top view showing the deck at least 6 cm wide spanning 25 cm between the banks, labeled materials (sticks, tape, clips, string, bands), every joint marked, and arrows showing the load's weight passing through the deck and side frames or supports to the tops of the banks.

Why: The sketch is evidence of a planned design and of understanding the load path; it also lets the group check the budget before building.

- Side and top views
- Materials and joints labeled
- Load path arrows end at the banks
- Dimensions consistent with the design rules

Version 1 materials and cost

Material	Quantity used	Unit cost	Cost
Craft sticks		1	
Tape (10 cm pieces)		1	
Paper clips		1	
Rubber bands		2	
String (10 cm pieces)		1	
Index cards		2	
Total			

Shaker calibration (strokes counted in 10 seconds)

Level	Target strokes in 10 s	Practice count 1	Practice count 2
1	20		
2	27		
3	33		

Version 1 test results

Stage	Load on deck? (Y/N)	Deck height at mid-span (mm)	Sag change since loaded (mm)	Joints loosened / broken	Rating	Target met? (Y/N)
No load						
Loaded, before shaking			0			
After Level 1						
After Level 2						
After Level 3						

Class comparison table

Group	Bridge type	Main design features	Cost (units)	Level 1 rating	Level 2 rating	Level 3 rating
1						
2						
3						
4						
5						
6						
7						
8						

3. Look across the class table. Which design features do the best-performing bridges share, and which features show up in bridges that failed early? Name at least two features and the groups that show them.

Answer: Depends on class data. Common findings: bridges with triangles in the side walls or diagonal cross-bracing, a low and wide shape, and a curb or rail on the deck earned the best Level 2 and Level 3 ratings; flat decks without curbs lost the load at Level 2; rectangle-only frames and tall, narrow structures folded or toppled; joints held by a single short piece of tape peeled first.

Why: The answer must come from the class table, naming groups and their ratings.

- At least two features named
- Each linked to specific groups and ratings
- Distinguishes features of successful and failing bridges

4. Redesign plan: which one main feature will you change for version 2, which test result is it meant to fix, and what do you predict will happen at each level?

Answer: Group-specific. Example: 'Our load slid off at Level 2, so we will add a curb of sticks on both edges of the deck (6 units). We predict No damage at Level 1, Minor damage at Level 2 and Damaged, emergency use only at Level 3.'

Why: A good redesign changes one main feature, tied to a specific failure, with a testable prediction.

- One main feature changed
- Linked to a specific test result
- Prediction for each level
- Stays within budget

Version 2 test results

Stage	Load on deck? (Y/N)	Deck height at mid-span (mm)	Sag change since loaded (mm)	Joints loosened / broken	Rating	Target met? (Y/N)
No load						
Loaded, before shaking			0			
After Level 1						
After Level 2						
After Level 3						

Analysis questions: answer key

5. Did version 1 and version 2 meet each of your criteria and stay within every constraint? Use the ratings, sag changes and costs from your tables.

Answer: Group-specific. A complete answer compares each version's rating at Levels 1, 2 and 3 with the target, quotes the sag changes and joint counts, and states both costs against the budget. Example: 'Version 1 met Level 1 (no damage, 1 mm) but missed Level 2 (load fell off; target was minor damage). Version 2 met all three (0 mm, 4 mm, then emergency use only) at 64 of 70 units.'

Why: Students must judge each criterion separately with the recorded numbers.

- Each level's rating compared with its target for both versions
- Sag or joint data quoted
- Cost compared with the budget

6. Pick the feature that made the biggest difference across the class (for example triangles, cross-bracing, a wide or low structure, a curb on the deck, or flexible connections). Explain, in terms of forces and motion, why it helped the bridge survive shaking.

Answer: Example (triangles and bracing): shaking pushes the bridge sideways back and forth because the deck's inertia resists each change in motion. A rectangular frame can lean into a parallelogram without any stick changing length, so the joints take all the strain and fail. A triangle cannot change shape unless a stick stretches, compresses or breaks, so a triangulated or cross-braced frame keeps its shape and spreads the force through the sticks. Other accepted features: a curb holds the load on the deck by blocking the sliding the shaking causes; a low, wide structure has a lower center of mass and a wider base, so it resists tipping; flexible connections or rubber-band pads let the deck shift slightly without breaking joints.

Why: The explanation should connect the feature to forces from the shaking (inertia, sideways sway, tipping, sliding).

- Names one feature supported by class data
- Explains how shaking loads the structure (sideways force, sway, sliding or tipping)
- Explains how the feature resists that effect

7. Level 3 moves the platform 3 times as far as Level 1 and about 1.7 times as often. Describe one way the shake table is a good model of earthquake shaking and two ways it is not like a real earthquake hitting a real bridge.

Answer: Good model: stronger levels move the ground farther and faster, like stronger real shaking, and every design meets the same measured motion, so comparisons are fair. Not like reality (any two): the table shakes in one horizontal direction only, while real ground also moves up and down and in many directions; real shaking mixes many frequencies and changes over time; the three levels span only about an 8-fold range in estimated acceleration, while real shaking ranges from barely felt to violent; the model bridge is tiny and light, so it vibrates differently from a real one; both banks move together, while the ends of a real long bridge can move differently; there is no soft ground that could amplify shaking or liquefy.

Why: Students should name a real strength and two specific, correct limitations.

- One accurate strength
- Two accurate, specific limitations

8. The three bridge types had different targets and budgets. Explain why a county would set a higher target and spend more on a lifeline bridge than on a farm-road bridge, using the idea that stronger shaking is rarer.

Answer: Frequent, moderate shaking will happen many times during any bridge's life, so every bridge must handle it. Rare, strong shaking may happen once or not at all, so a farm-road bridge may be allowed to be damaged and closed as long as it does not collapse. A lifeline bridge is needed most right after a strong earthquake, when ambulances must reach the hospital, so the county accepts a higher cost to keep it open even in rare, strong shaking. Spending lifeline money on every bridge would use up the budget for other safety needs.

Why: This applies the lesson's chart logic: match performance to importance and to how often each level of shaking occurs.

- Links lower targets to the rarity of strong shaking
- Explains why a lifeline must work after an earthquake
- Mentions cost or trade-off

9. List three things the class kept the same so that the designs could be compared fairly. Then name one thing that may still have made the comparison unfair and how you would fix it.

Answer: Kept the same (any three): the 25 cm gap and bank height; the 100 g load at mid-span; the stroke distance, beat rate and duration of each level, checked by stroke counts; the order of levels with no repairs; the same rating rules. Possible remaining unfairness: different shakers shook slightly differently or hit the rim with different force; fix by having one trained shaker test every bridge at a station, or by marking the stroke and counting for every test. Other answers: rollers or rubber bands differ between tables (use identical kits); sag measured at different points (mark mid-span).

Why: A fair comparison depends on controlled shaking, load and judging; the shaker is the most variable part.

- Three controlled variables
- One plausible remaining source of unfairness
- A practical fix

10. After the 1995 Kobe earthquake, Japan placed many new buildings on rubber-and-steel bearings, and parts of the new Bay Bridge span are designed to bend and absorb energy so the main structure is protected. Did any bridge in your class use a similar idea? Explain how letting part of a structure move or bend can reduce damage.

Answer: Example: 'Group 4 set its deck on rubber-band pads instead of taping it to the banks. During Level 3 the banks moved but the deck lagged behind and stretched the bands instead of breaking joints.' Letting part of a structure move or bend means less of the shaking's energy goes into breaking the main frame: isolators let the ground move under a building or deck so the structure above shakes less, and parts designed to bend absorb energy and can be replaced after the earthquake while the main structure stays intact.

Why: This links classroom observations to real mitigation technologies the lesson and slide 24 mention. If no group tried such an idea, students can propose how they would.

Also acceptable: If no group used the idea, full credit for a clear proposal of how to add an isolator or a replaceable 'fuse' part to their own bridge.

- Identifies a design (or proposes one) that lets part of the structure move or bend
- Explains that this reduces force or absorbs energy so the main structure is protected

Individual evidence of learning

Each student submits their own copy of the design brief, the version 1 sketch, the test tables and individual answers to q5 through q10. The design brief and q1 are the evidence of defining precise criteria and constraints (MS-ETS1-1); q3, q5 and q6 show systematic comparison of designs using test data (MS-ETS1-2); q8 and q10 connect the design to earthquake mitigation.

Assessment criteria

Criterion	Proficient looks like
Precise criteria and constraints	Every criterion in the brief is measurable with the ruler or rating scale and matches the bridge type's targets; budget, materials, time and the no-river-support rule are stated as constraints.
Fair test	Shaker calibration counts are recorded within 2 of the targets; levels run in order without repairs; sag and joint data recorded at every stage.

Data-based comparison	Uses the class table to identify at least two features linked to success or failure, citing specific groups and ratings.
Redesign and evaluation	Changes one main feature for a stated reason, predicts the effect, and judges version 2 against the same criteria with numbers.
Model and mitigation reasoning	Names a real strength and two real limitations of the shake table, and explains why importance justifies different targets and budgets.

Accessibility adaptations

- Provide pre-cut 10 cm tape pieces in a cup and pre-sorted material kits so budgeting is counting, not measuring.
- Offer a starter photo card of three basic bridge forms (beam, truss, arch) for students who freeze at a blank build.
- Let a student with limited fine-motor control take the shaker, measurer or recorder role; use a large-print ruler and an enlarged rating scale.
- Use a visual timer for the 25-minute build and give a two-minute warning; accept a labeled photo plus a spoken explanation in place of the written sketch.

Low-cost alternative

Without trays, set a sheet of stiff cardboard on six round pencils directly on a desk and tape two books to the desk as stops at 1, 2 and 3 cm. Rolled newspaper tubes or index-card strips can replace craft sticks, and a juice box or a cup of washers can replace the penny bag, as long as every group uses the same load.

Model limitations

This lab has not been physically tested as written; the stroke distances, beat rates and rating thresholds are reasonable starting values that a teacher may need to adjust after a trial run. Hand shaking only approximates a steady back-and-forth motion: at the stated rates the estimated peak accelerations are only about 0.04 g, 0.14 g and 0.34 g, and the stops add jolts. The table moves in one horizontal direction only, while real ground motion mixes many frequencies and directions, including vertical motion, for seconds to minutes. A craft-stick bridge is tiny and light compared with a real bridge, so it vibrates much faster and its resonance does not scale to real structures; tape and wood behave differently from steel and concrete. Both banks sit on the same platform and move together, whereas the two ends of a long real bridge can move differently, and soft ground can settle or liquefy beneath real supports. The ratings are classroom stand-ins for real performance levels.

Teacher notes

This lab has not been physically tested; run one bridge through all three levels yourself before class and adjust stroke distances or tempos if every bridge survives Level 3 or none survives Level 1. A useful target is that a simple taped plank survives Level 1 but loses its load at Level 2. The rating scale's thresholds (2 mm and 5 mm of added sag, 2 loosened joints) can also be adjusted, but announce any change before testing. For a math extension, the estimated peak accelerations (assuming smooth back-and-forth motion) are about 0.04 g, 0.14 g and 0.34 g for Levels 1, 2 and 3, from $(2 \times \pi \times \text{frequency})^2 \times \text{stroke half-distance}$, with

frequencies of 1.0, 1.33 and 1.67 cycles per second. The performance-target table matches slide 24 and Lab 3, and is this chapter's own simplified version of performance-based design, not a copy of the textbook's Figure 5.