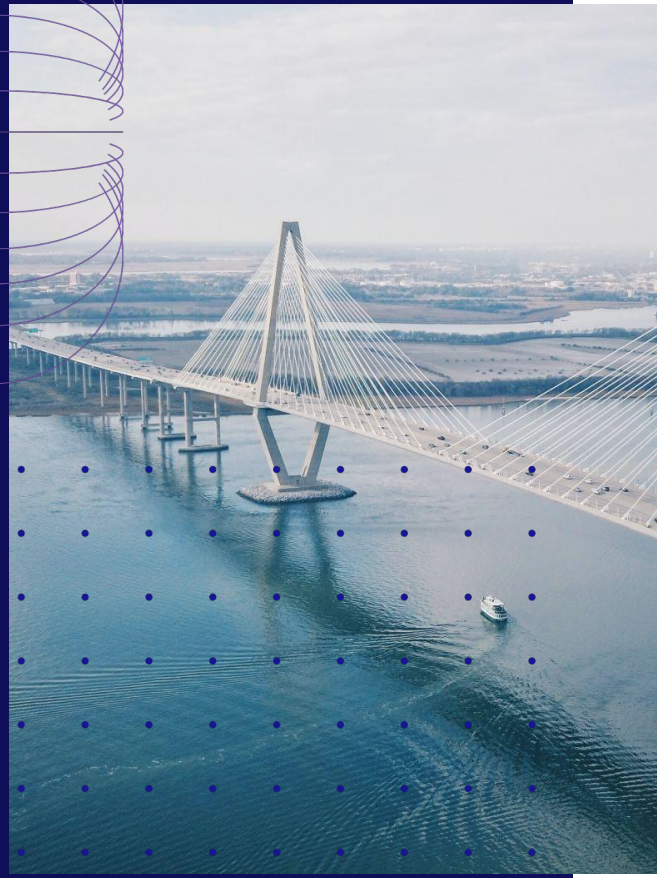


Engineering Tomorrow

Bridges

Building Structures That Last

GOAL

To design and create a bridge that withstands a certain amount of stress.

2024-08-15_v1.0

Breakout Development Team

JOANNA CAUDLE

College: Georgia Institute of Technology
Major: Mechanical Engineering
Industry Experience: Bechtel Power Corporation

KIERA MALLINSON

College: University of Notre Dame ‘22
Major: Electrical Engineering

CAROLINE GILLESPIE

College: Notre Dame ’23
Major: Mechanical Engineering

Extension Development Team

MILTON DAVIS

College: Purdue & John Hopkins
Major: Aerospace Engineering
Industry Experience: NASA, GE, UMD

CONNOR FRATANTARO

College: Bucknell University
Major: Mechanical Engineering

SARAH McCLELLAND

College: Bucknell University
Major: Mechanical Engineering

Team Roles

Lead Design Engineer: After the group as a whole discusses which bridge design to follow, the lead designer(s) will create a full-size sketch of the side and bottom design of the bridge for the builders to use as reference while assembling the bridge. The lead designer role is also in charge of measuring and dimensioning the sketch to ensure that it meets all length criteria set by the interactive notebook.

Simulation Analyst: (1 Student) As part of the redesign process, the simulation analyst will work with the other members of the group to design alternative bridges. They will also need to analyze simulated forces they will apply to their designs. Report the data to teammates and work together to select an optimized final bridge design.

Assembly Expert: (1-2 Students) Student(s) in this role will undertake the actual building of the bridge. Groups should discuss which materials to use and what design to follow as a whole before the assembly experts begin to build the bridge model. Multiple students can partake in this role - ideally each student would be focused on each of the bridge parts: each individual side of the bridge, the bottom road, and the connecting top of the bridge.

Data & Test Engineer: (1-2 Students) The data engineer collects and records the experimental data that the lab provides. This includes measuring the weight applied to the bridge and documenting when the bridge reaches failure. The data engineer alsos record the material costs of the project. Data engineers must work with the assembly experts to balance maximizing structural strength with minimizing the cost of the project.

What is the Significance of Bridges?

ANSWER ME!

If there were no bridges, how would our society change?

Type Your Answer Here

Bridges Build Connections

"Poverty due to rural isolation is a crisis that we can solve."
—Avery Bang

Avery Bang studied Civil Engineering & Studio Art; she is the former President & CEO of Bridges to Prosperity and is currently the **Senior Principal of the Mulago Foundation**.

DID YOU KNOW?

- Over **1 billion** people don't have safe year-round access to education, healthcare and markets
- Access to bridges raised average income levels 30% as farms became more efficient and access to jobs increased

How can bridges help those in poverty?

ANSWER ME!

Type Your Answer Here

Even though bridges have different looks and purposes...

SUPPORT INTEGRATED TRANSPORTATION SYSTEMS

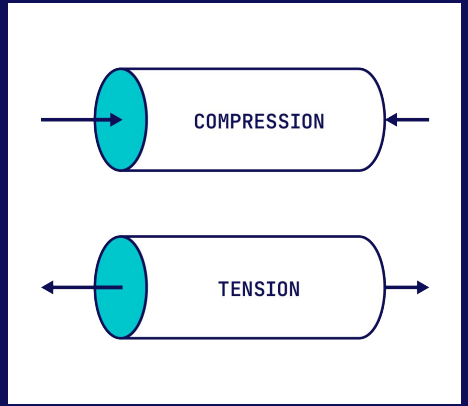
TRAVERSE CHALLENGING SPANS OF WATER: 7,700 Foot Floating Bridge in Washington

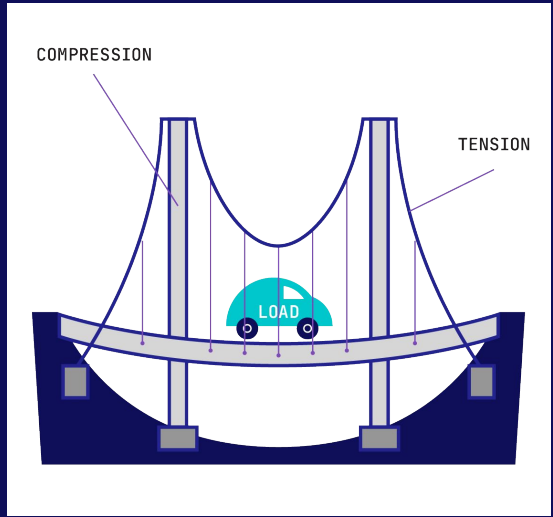
AID ACCESS IN DISASTERS ZONES: Mobile Origami Bridge

ADD BEAUTY THROUGH INNOVATIVE DESIGN: Octavio Frias de Oliveira Bridge has a single concrete mast to hold curved tracks

… all bridges have the same design fundamentals!

- Engineers **Balance Forces** to ensure stresses & strains are within safe ranges.
- **Compression and Tension stresses** exist throughout the structure, and are modeled under the **most severe conditions**.
- **Understanding Stress & Strain** relationships is fundamental in choosing bridge materials and design.





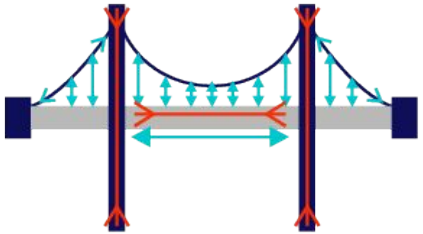
Bridge Design Options

Bridge design is a blend of mechanical, civil, structural, and materials engineering, along with architecture and art!

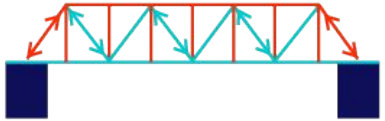
BUILDING BLOCKS: Beams, Plates, Cables, Cylinders, Triangles

MATERIALS: Wood, Stone, Concrete, Iron, Steel, Asphalt

BEAM

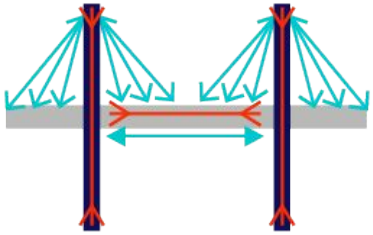


SUSPENSION

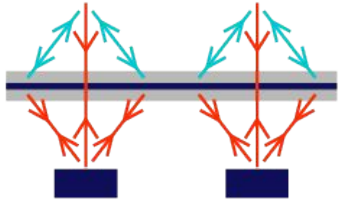


TRUSS

ARCH



CABLE-STAYED



CANTILEVER

TENSION

COMPRESSION

Try This!

Using the last slide, match the bridges to their structure names:

ARCH

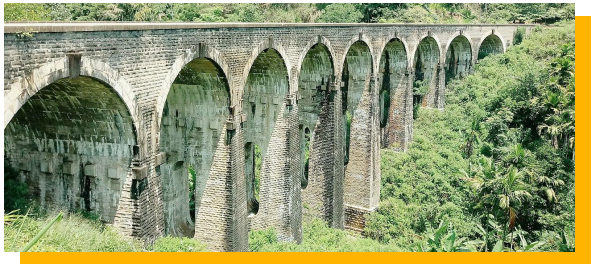
CABLE-STAYED

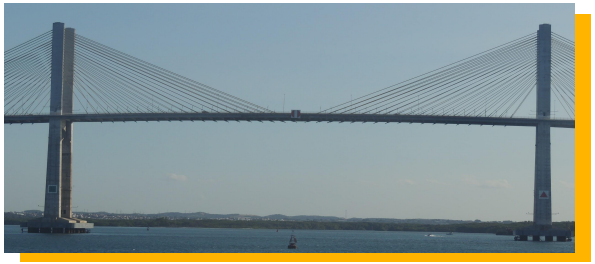
BEAM

TRUSS

SUSPENSION

CANTILEVER



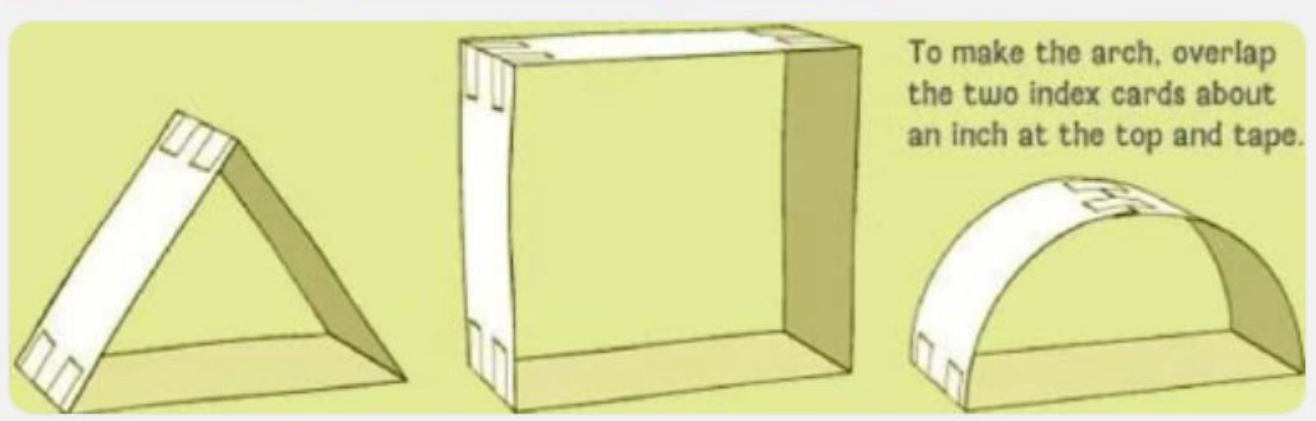


So...which shape is the strongest?

Using tape to hold index cards together, you will build different shapes and assess their strengths!

BASIC SHAPES TO CONSIDER:

Truss/Triangle | Rectangle | Arch

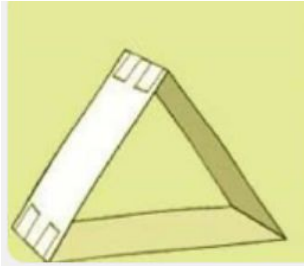


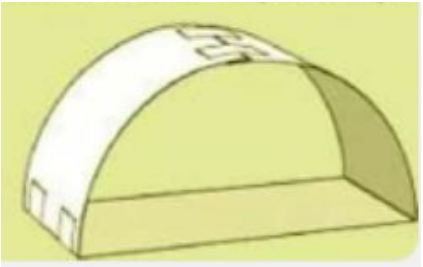
Try to make each build fall by gently pushing

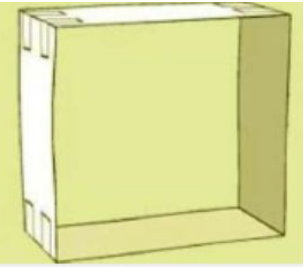
Results!

You should notice that the shapes rank in the following order:

STRONGEST







WEAKEST

These are the shapes you should use in your bridge design.

The sides of triangles are very **rigid**, which allows them to transfer force more evenly through their sides than other shapes. As a result, a triangle can withstand a lot of **strain**, making this particular shape very strong.

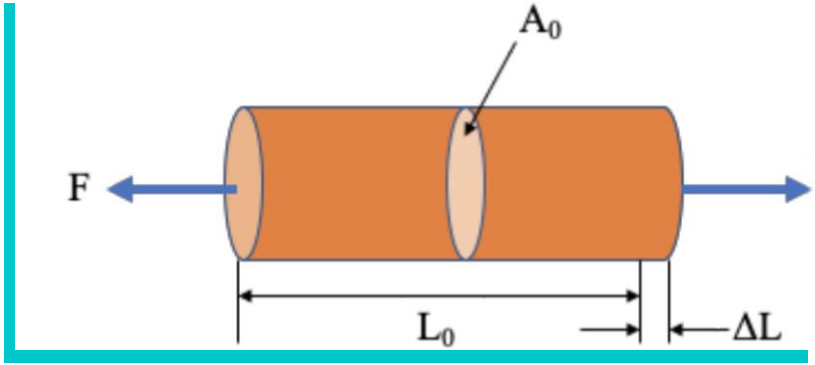
Stress & Strain Fundamentals

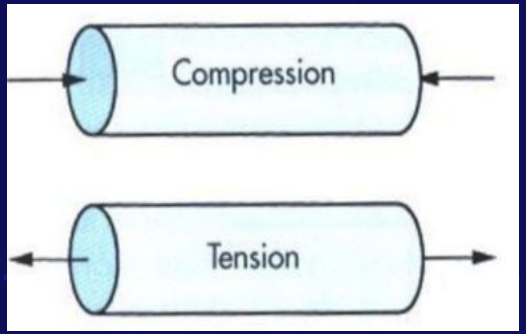
- **Stress (σ)**
  - Force per cross-sectional area
  - Units: pascals or psi

$$\sigma = \frac{F}{A_0}$$

- **Strain (ε)**
  - Percent of deformation from the stress force
  - Unitless measurement

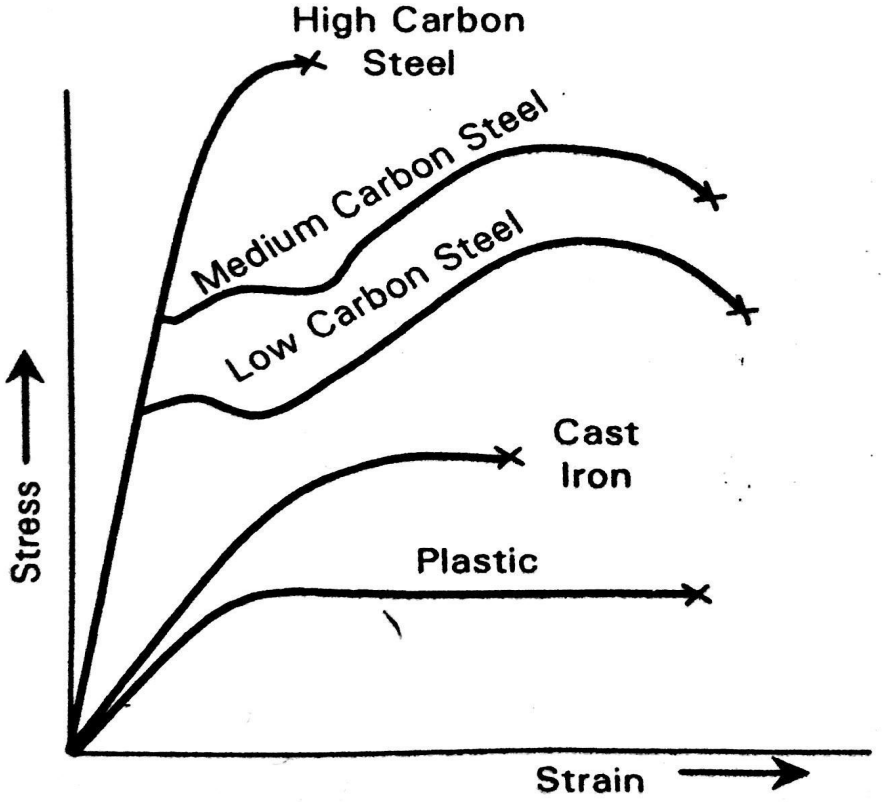
$$\varepsilon = \frac{L - L_0}{L_0}$$





In a tensile test, a sample is pulled from both ends (stressed) and the deformation (strain) is measured, until it breaks (fails).

This graph shows tensile stress versus strain curves for various types of materials



Which material fails with the most deformation (highest strain)?

Type your answer here.

Which material fails at the highest stress?

Type your answer here.

Which material deforms the most from the least amount of stress?

Type your answer here.

Real Steel Bridges

RECALL

These three bridges connect Edinburgh with northern Britain. They are all made out of steel but are very different in appearance.

Can you tell which designs they represent? Match the bridges to their structure names below.

CABLE-STAYED

SUSPENSION

CANTILEVER

Plan Your Bridge Build...

WATCH ME!

This video will be a good introduction for this challenge!

In the rest of this lesson, your group will create a bridge model.

You will do this by using the Engineering Design Process in order to answer the question:

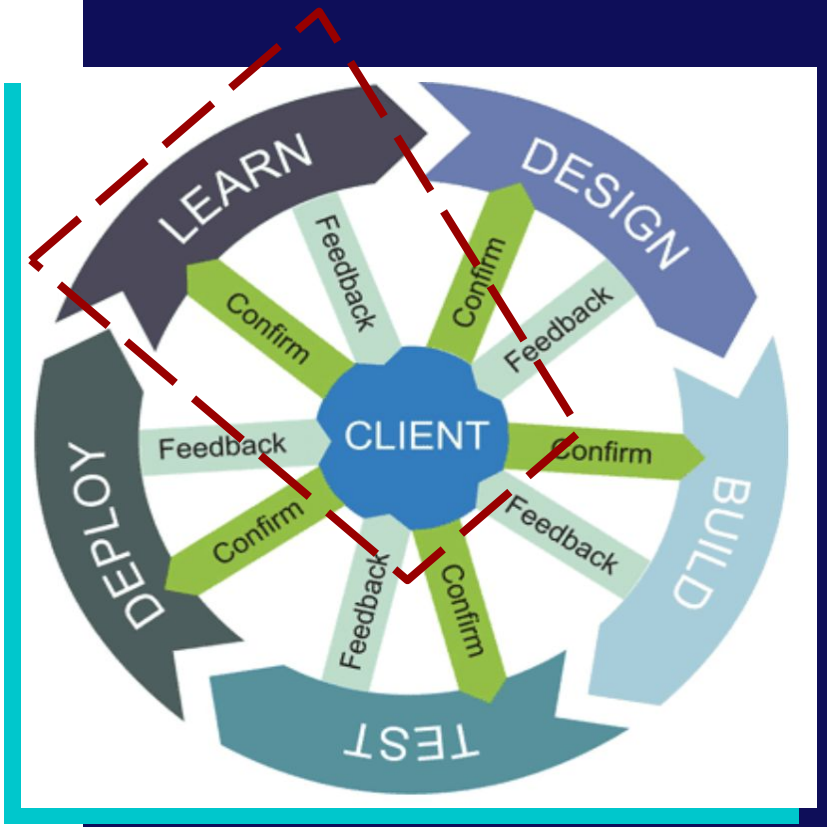
How can we create a bridge model strong enough to hold the maximum load?

The Engineering Design Process

THINK: IMAGINE YOU ARE A TEAM OF CIVIL ENGINEERS

- How can you use the Engineering Process to create a bridge that is able to withstand the greatest amount of stress (weight)?
- What action would you do with each step of the process?

Click HERE for more information on the Engineering Design Process!



The Components for Building your Bridge

For Testing

1 x Mending Plate

2 x Zip Ties

1 x S Hook

For Building

Dowel Rods

Popsicle Sticks

For Fastening

Masking tape
Duct tape
Hot Glue
(optional)

Step One: Identify the Problem

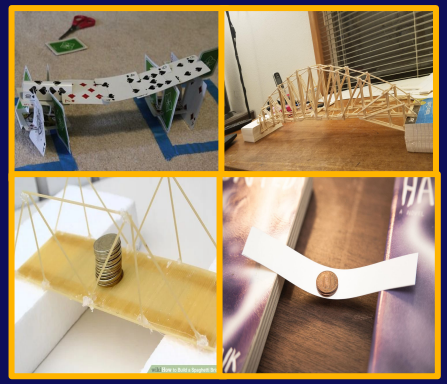
What problem or challenge are you trying to solve?
Does your team want to build the strongest bridge? The most elegant? The lowest cost bridge? A bridge that can easily be built in a remote region (perhaps consider how some parts could be pre-built and shipped to aid in construction on site)? Type your answer here.

Step Two: Research

Given the materials you have, what design could you use? Do some research on different types of bridge designs. Does one stick out to you in particular? It is very important to have some design ideas before moving into prototyping. See below for some examples!

Type Your Answer or Insert Pictures of Possible Designs Here

BRIDGE EXAMPLES



POSSIBLE MATERIALS

Design & Testing Restrictions

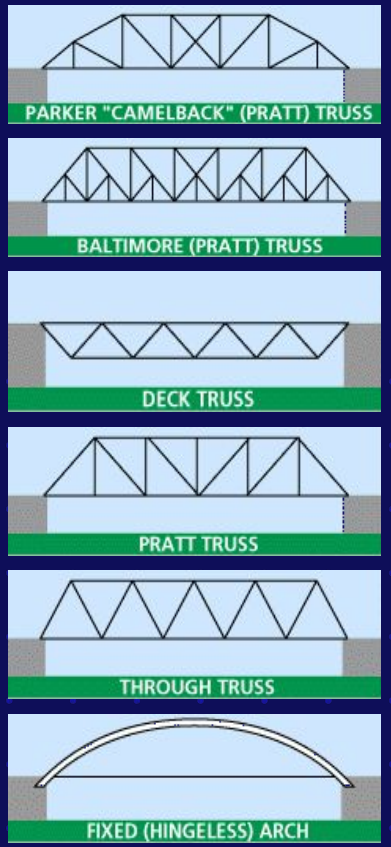
DESIGN CONSTRAINTS

- Bridge must be **12 inches or more in length**.
- Bridge must be **3 inches or less in width**.
- Bridge can be as tall as you need.
- Use **materials** found at home or in your **ET Toolkit** to build the bridge (popsicle sticks, spaghetti, wood dowels, etc.).

TESTING RESTRICTIONS

- You will need two chairs or two tables to test your bridge. Set the chairs/tables up **11 inches apart**.
- Place your bridge model on the chairs/tables. Each end of the bridge should **extend at least 1 inch** beyond the chairs/tables.
- Test the strength of your bridge using a **shopping bag**. Add small items until it breaks and **calculate** the weight of all the items in the **bag**.
- Use the iterative process to build a stronger structure.

SOME DESIGN IDEAS



Step Three: Design your Solution

Draw out a diagram of your group's design.
Be sure your bridge meets the design constraints on the previous slide (slide 22).

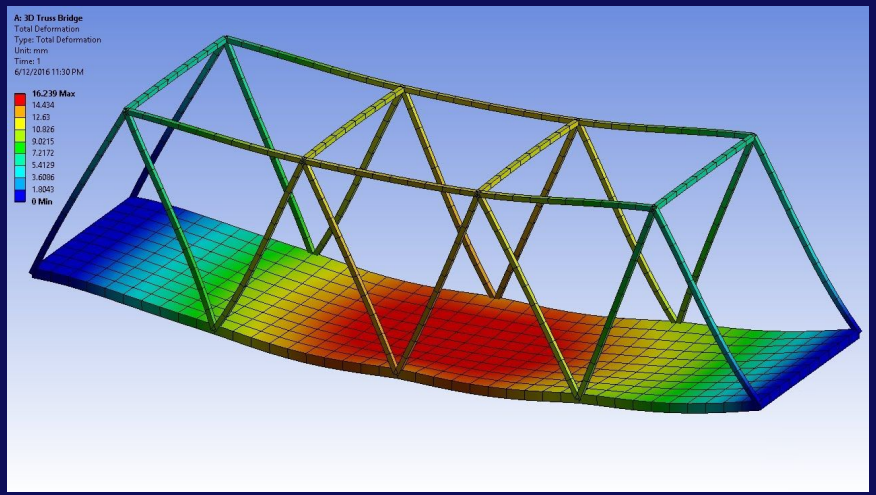
Insert photos or drawing here.

WHAT STEPS WILL YOU USE IN YOUR BUILD AND WHY?

Type Your Answer Here.

OPTIONAL Part 2

Force Analysis Simulation



If directed by your teacher, model your bridge design using the force analysis simulation discussed on the next slides.

If not, go to **slide 33**

Force Analysis Simulations

How do simulations work?

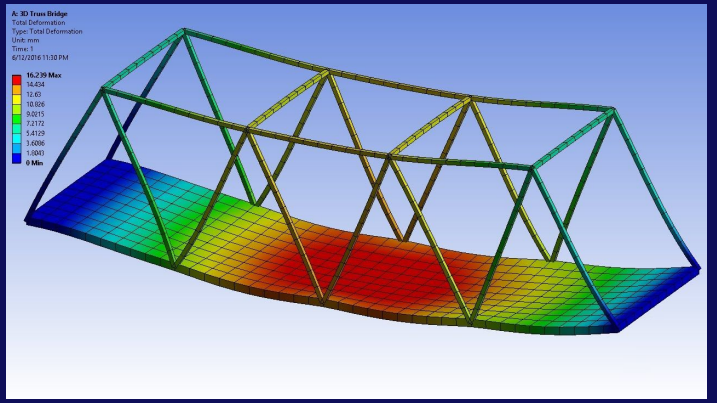
Simulations use computing power to quickly solve a large amount of algebraic equations.

Why use a simulation?

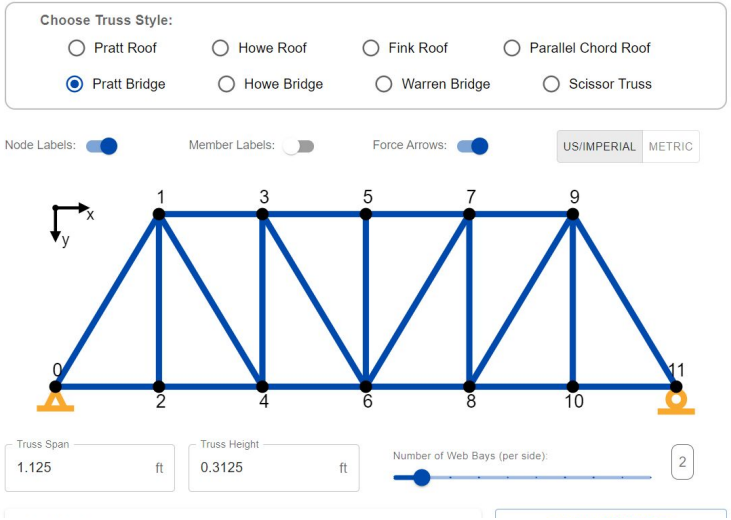
They help us create safer designs without having to waste expensive test materials.

Can we trust them?

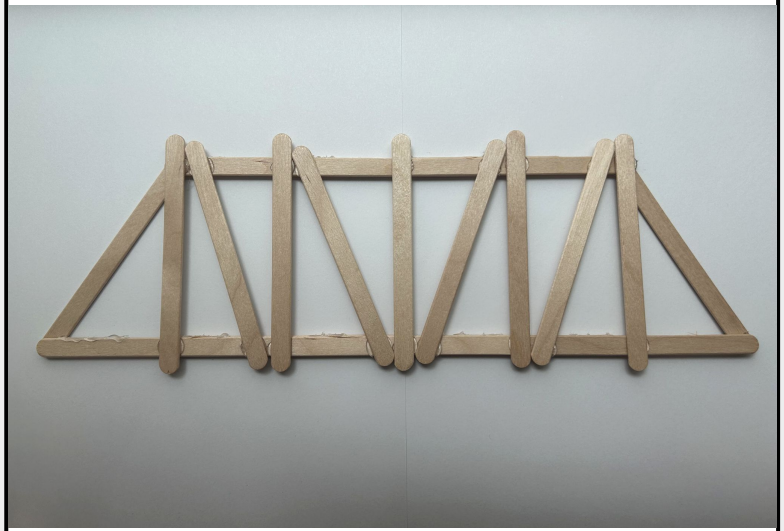
We prove the accuracy of our simulations by comparing simulated results to observations.



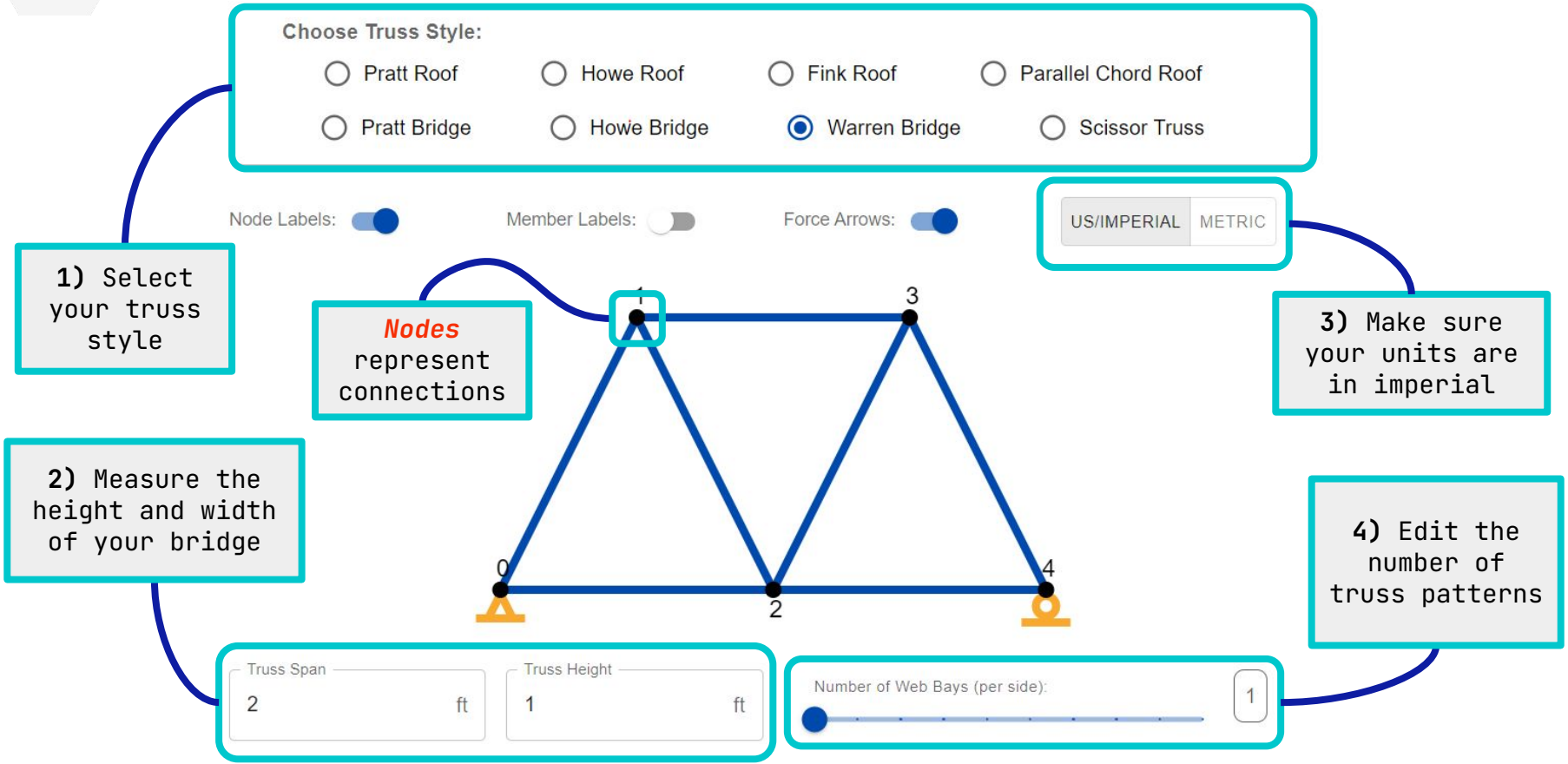
Design A Bridge...



Then Build It!



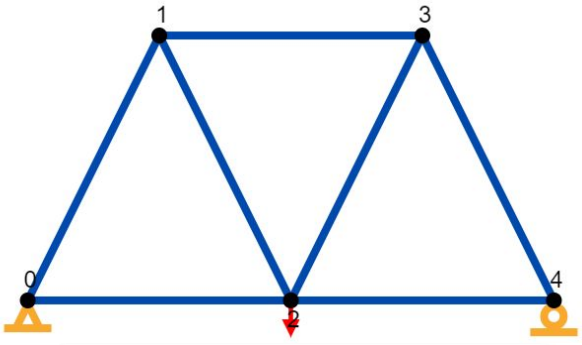
Click HERE for Analysis Software



Calculator Inputs

Apply Forces

- Open the “Truss Loading” tab.
- Find the middle *node* on the bottom layer of the bridge.
- If there are two center nodes apply 50 kips to both
- Add a force of 100 kips under the Fy column
- Click “Calculate Forces” on the webpage.



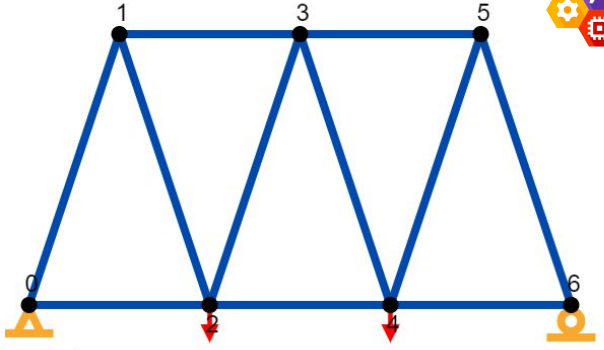
Truss Loading

TOP NODES:	Fx	kips	Fy	kips
BOTTOM NODES:	Fx	kips	Fy	kips

RESET FORCES TO ZERO

Individual Node Forces

Node	Fx (kips)	Fy (kips)
0	0	0
1	0	0
2	0	14
3	0	0
4	0	0



Truss Loading

TOP NODES:	Fx	kips	Fy	kips
BOTTOM NODES:	Fx	kips	Fy	kips

RESET FORCES TO ZERO

Individual Node Forces

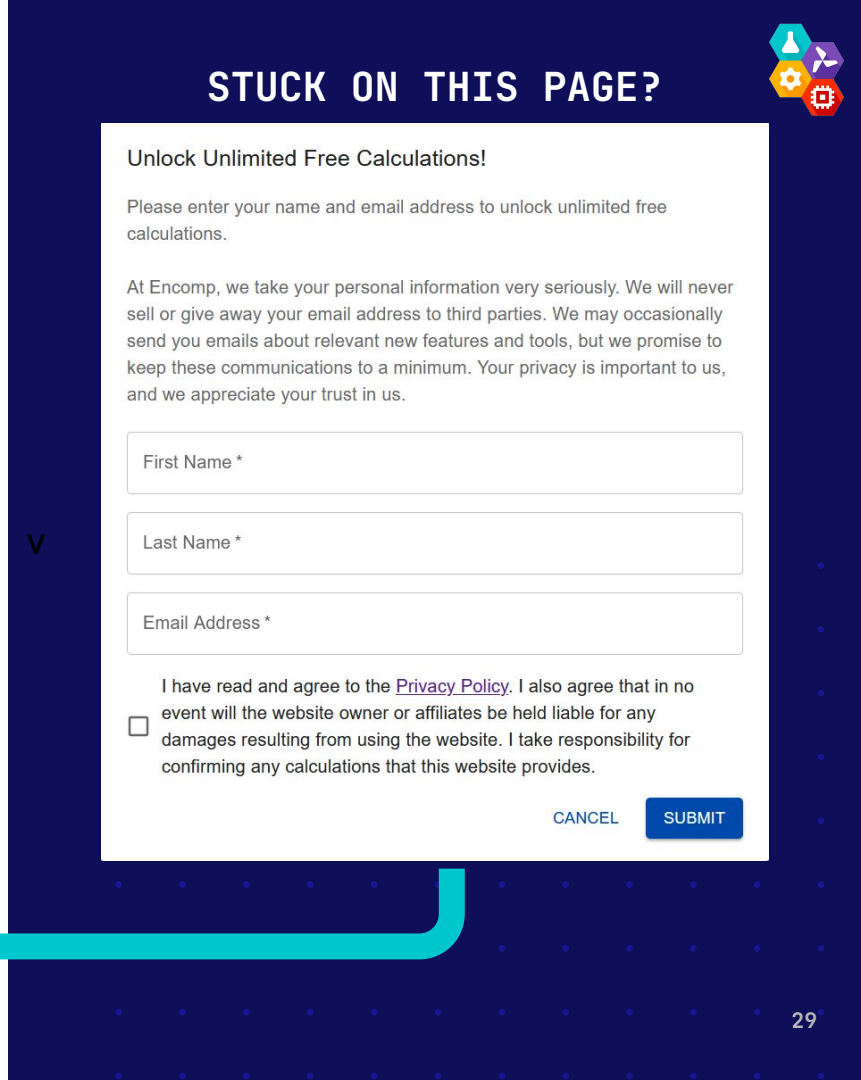
Node	Fx (kips)	Fy (kips)
0	0	0
1	0	0
2	0	7
3	0	0
4	0	7
5	0	0

Analyze Your Results

Interpreting Results

- Run the force calculations for multiple designs
- Identify one design that minimizes the forces in the beams
- Try and minimize the number of beams to reduce cost

1) Try a new browser
2) Move to a new computer
3) Sign up for more trials



Analyze Your Results

Expand the “show calculations” page and find Section 3.6

Using section 3.6 and the color map, which beams hold the most force?

Type your answer here...

Rank the materials from strongest to weakest.

Type your answer here...

How will you use different materials to build a strong but affordable bridge?

Type your answer here...

Upload Your Results

UPLOAD A SCREENSHOT OF YOUR DESIGN

Use “Calculate Forces” to see the color map on your design.

Insert photo here.

Step Four: Redesign your Solution

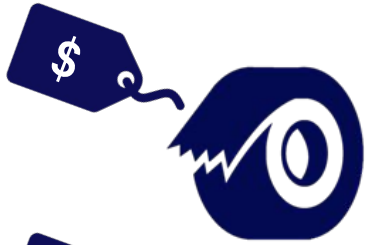
How has your original bridge design changed after using the simulation tool? Why did you make these changes?

Type your answer here...

HOW WILL YOU USE THE FORCE CALCULATIONS TO CHOOSE YOUR MATERIALS?

Type Your Answer Here.

Step Five: Making Good Connections



Use more than 1 piece of tape.

Hold joints together for 3 to 5 minutes.

Let cool for 30 to 40 seconds.

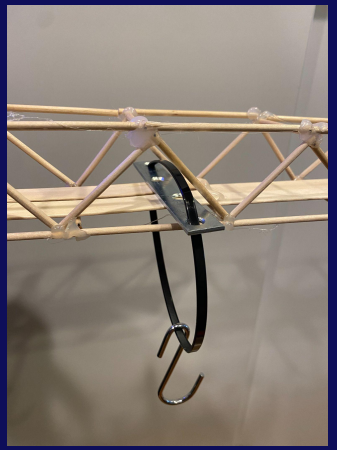
A successful bridge needs good connections between beams without putting the project over budget.

HOW DID YOU MAKE YOUR CONNECTIONS AND WHY?

Type Your Answer Here.

Step Seven: Test

LOAD YOUR BAG!



To calculate the weight your bridge can hold, put a bag on your hook and load it until it breaks.

Then calculate the weight of the items in the bag.

Step Eight: Analyze Results

Calculate the cost of your bridge.

Material	Cost
1 Small Dowel	$5
1 Medium Dowel	$10
1 Large Dowel	$20
1 Popsicle Stick	$4
1 Piece of Spaghetti	$1
2 in. Piece of Duct Tape	$2
1 Stick of Hot Glue	$10

- How much does your bridge cost?

$ _____ . ___

NOTE: *If you used materials from home that are not listed, then this question is optional.*

Step Eight: Analyze Results

Calculate the weight of the items you used.

Items	Weight in Ounces

- How much does your bridge weigh?

_____ Ounces

_____ Pounds

Step Eight: Analyze Results

$$structural\ efficency = \frac{maximum\ weight}{bridge\ weight}$$

Calculate the structural efficiency of your bridge.
How does this compare to your expectations?

Type Your Answer Here.

Use your observations & data to answer the questions.

What was the structural efficiency of your bridge?

_____ %

Reflection

ANSWER ME!

What do you think went well when completing this activity?	What is something you would do differently if you were to do this again?	If you had to cut the cost of your bridge by $1.00, what would you change?
Write your answer here	Write your answer here	Write your answer here

Complete the mandatory 5-minute **Exit Ticket** by clicking here!

Continue to Explore

- **IF YOU LIKED TODAY'S BREAKOUT, YOU MAY BE INTERESTED IN THESE TOPICS:**
  - Bridge Design
  - Tunnel Design
  - Construction Materials
  - Concrete and Steel Rebar
  - Latticework in Buildings

- **TYPES OF ENGINEERING RELEVANT TO TODAY'S WATER TREATMENT BREAKOUT:**
  - Civil Engineering
  - Environmental Engineering
  - Architectural Engineering
  - Materials Engineering
  - Mechanical Engineering

Continue to Explore

OPTIONAL: THROUGHOUT HISTORY,HOW HAVE ENGINEERINGS IMPROVED BRIDGES VIA SHAPE, MATERIAL, AND APPEARANCE?

Type your answer here.

Thank you!