Activities may be standalone, or part of lessons or curricular units.

TE Activity: Breaking the Mold

Summary
In this math activity, students conduct a strength test using modeling clay, creating their own stress vs. strain graphs, which they compare to typical steel and concrete graphs. They learn the difference between brittle and ductile materials and how understanding the strength of materials, especially steel and concrete, is important for engineers who design bridges and structures.

Engineering Connection
Engineers want to know the properties of materials in advance of using them in a project so they can design the structure to be strong enough to stay safe (not fail) under its anticipated forces and stresses. Thus, strength of materials is a significant area in engineering design because engineers want to be able to make informed decisions about construction materials. Many engineering companies have a team dedicated to researching and selecting the optimal materials for their products and projects to make sure their designs work dependably and last a long time.

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Grade Level: 7 (6-8)  
Group Size: 2
Time Required: 50 minutes  
Activity Dependency: None
Expendable Cost Per Group: US$ 1
Keywords: bridge, brittle, compression, compressive, concrete, ductile, elasticity, force, mate member, modulus of elasticity, steel, strain, strength, strength of materials, stress, tensile, ten
Reviews: Read Reviews | Be the First to Write a Review

Related Curriculum:
subject areas  Physical Science
Pre-Req Knowledge (Return to Contents)
Students should have a basic understanding of compressive and tensile forces, in relation to the bridges and beams. Students should also know that steel and concrete are two common material design. A discussion of these materials can be found in the background of this activity as well as lesson, Strength of Materials.

Learning Objectives (Return to Contents)
After this activity, students should be able to:

- Define several engineering terms such as stress, strain and elasticity.
- Use calculations to determine the material properties of clay.
- Construct and analyze graphs to compare properties of different building materials used in

Materials List (Return to Contents)
Each group needs:

- 6 or 7 books, each smaller than 1-inch (2.5-cm) thick, totaling ~ 10 lbs (~4.5 kg)
- Modeling clay piece, 1 inch x 1 inch x 3 inches (2.5 cm x 2.5 cm x 7.6 cm)
- Wax paper or plastic wrap, to keep clay pieces from drying out
- Measuring stick or ruler with 1/16-inch (1-mm) marks
- Materials Data Sheet, one per person

For the entire class to share:

- Scale, to weigh books
- Scrap paper
- Tape

Introduction/Motivation (Return to Contents)
Who benefits from a bridge? How? (Possible answers: Me, my family and businesses - for work family or friends, shopping, travel.) How do the needs of a community dictate the characteristics (Possible answers: A bridge meets a community's need to access resources; for commerce and expansion; to be connected to another community, city or region; and to overcome specific envi obstacles such as rivers or gorges.) How important is it for us that our bridges do not break or fa suggestions from the students.)

What materials would you use to build a bridge? (Gather suggestions from the students.) These days, two main materials are used to construct bridges: steel and concrete. While several other types of materials can be used, they are not as popular or as commonly-used as steel and concrete. It is important for engineers to be able to measure the strength of these materials so that they can properly design bridge members (components) to handle the anticipated amount of compressive and tensile forces from the environment and traffic.

What types of forces must the materials of a bridge be able to handle? Stress ($\sigma$) is basically the applied forces acting on the material. Strain ($\varepsilon$) is basically the change in shape of the material when a stress is applied. As you can imagine, stress and strain are related to each other. Tensile strength is the amount of tensile stress that a material can resist before breaking, cracking or failing. Compressive strength is the amount of compressive stress that a material can resist before breaking, cracking or failing. A material that exhibits ductile properties to large strains before it fails, meaning that it can bend easily. A material that exhibits brittle prop or no yielding before failure. Elasticity is the ability of a material to return to its previous shape at released.

To better understand these prop engineers examine graphs of str called stress-strain diagrams. (Draw the Figure 1 graph on the board for everyone to see). For e
typical stress-strain diagram for materials, steel and concrete. The points of each of these curves represent the point at which the material begins to fail. The concrete curve shows an increase in strain and stress before rupture. That tells us that when concrete fails we should expect little or no warning type of material. Now look at the steel curve. Just before its breaking point, the curve shows a reduction in stress and strain continues to increase. That tells us that when steel fails we can expect a type of warning, usually in the form of changes in the material. Because of this behavior, steel is considered a ductile material.

(Optional: Show students an online interactive tool to illustrate visually the properties of wood, aluminum, brick, concrete, reinforced concrete, cast iron and steel. Use a fun mouse-controlled drag to stretch or squeeze material to failure. See WGBH's Building Big: Materials Lab website at http://www.pbs.org/wgbh/buildingbig/lab/materials.html)

Today, we are going to test the strength of a piece of clay, and calculate how it compares to steel and concrete in its material behaviors. Engineers would do similar calculations to determine the strength of a material or mixture of concrete before choosing a material to use in the design of a bridge.

**Vocabulary/Definitions**

- **Brittle**: The inability of a material to deflect or yield before failure.
- **Compression**: A pushing force that tends to shorten objects.
- **Compressive strength**: The amount of compressive stress that a material can resist before failing.
- **Concrete**: A combination of cement and aggregate into one solid mass. Example: Gray cement and water were mixed to create our concrete sidewalk.
- **Ductile**: The ability of a material to be subjected to large strains before it ruptures or yields.
- **Engineer**: A person who applies her/his understanding of science and math to creating the benefit of humanity and our world.
- **Member**: A constituent part of any structural or composite whole, such as a subordinating structural beam, column or wall.
- **Modulus of elasticity (E)**: Indicates the stiffness of a material.
- **Reinforced concrete**: A concrete member with steel embedded inside it to resist tensile forces.
- **Steel**: Refined iron that contains virtually no impurities.
- **Strain**: The elongation or contraction of a material per unit length of the material.
- **Stress**: Applied load divided by the material area it is acting on (typically the cross-sectional area of the member).
- **Tensile strength**: Applied load divided by the material area it is acting on.
- **Tension**: A pulling or stretching force that tends to lengthen objects.

**Procedure**

**Background**

Steel is created by eliminating most of the impurities found in iron. Engineers test various types of steel so they know what to expect when it is used as a construction material. Figure 2 shows an example of a steel beam being tested to failure. Some advantages to using steel for bridge construction include:

- Steel is very strong in both tension and compression and therefore has high compressive and tensile strengths.
- Steel is a ductile material and it yields or deflects before failure.

Some disadvantages to using steel are:

- Steel is expensive compared to concrete and wood.
- Steel can rust when exposed to some environmental conditions thus reducing its strength.

Figure 1. Typical stress-strain diagram for steel and concrete. click for copyright
Steel is a heavy material and thus reduces the allowable span of the member when co for use as a beam.

Cement is an ingredient used to make concrete. Cement is a powder; concrete is a solid m a Cement hardens when mixed with water. Concrete is made with cement, aggregate (gravel and water. Engineers test various "recipes" for concrete so they know what to expect when as a construction material. Figure 3 shows an example of concrete that was tested to failure. Sometimes other materials are added to the concrete mix to give it specific characteristics r with plain concrete mixes, making the concrete less brittle, stronger, more durable, a better or less likely to suffer freeze-thaw damage.

Some advantages to using concrete for members of a bridge:

- Concrete is extremely strong in compression and therefore has a high compressive strength.
- Concrete is inexpensive compared to steel.
- Using forms, concrete can be made into practically any shape.

Some disadvantages to using concrete:

- Concrete is a brittle material and can crack or break without any warning.
- Concrete is very weak when a tension force is applied to it and therefore has a very low tensile strength. (To address this weakness, steel is often embedded within the concrete at locations where tension forces are known to exist, making reinforced concrete. In a concrete beam, the steel would be placed along the bottom of the beam.)
- Because a certain amount of time is needed for hydration to completely occur, concrete members do not gain their full strength until much time has passed.

Before the Activity

- Form the modeling clay into pieces that are 1 inch x 1 inch x 3 inches (2.5 cm x 2.5 cm tall, one piece per student team. Make sure the base is 1 inch x 1 inch (2.5 cm x 2.5 cm cross-sectional area = 1 in² (6.35 cm²). Wrap the clay in wax paper or plastic wrap to k drying out.
- Weigh the books and tape to each a piece of paper with its weight written on it. Be as e
possible when weighing the books.

- Gather materials and make copies of the [Materials Data Sheet](http://www.TeachEngineering.org). one per person
- Divide the class into teams of two students each.

**With the Students**

1. Discuss with students the two most popular materials used in bridge construction: steel and concrete (as provided in the Introduction/Motivation section). Explain that today they will use clay and calculations to create their own stress vs. strain diagrams just like the ones used in engineering analysis, and compare them to the same diagrams for steel and concrete.

2. Have each group place the clay piece on a flat table or desk. Orient it so that it is standing vertically. Use a measuring stick or ruler to measure the initial height of the clay and record it on the data sheet. Have students record the number of books (in this case, the total weight of the books). Now, take the book just used, and a second book, and balance them both on top of the clay, leaving them there for about 5 seconds. What happens to the clay when two books are placed on top? (Answer: The clay should get even shorter.) Remove the book and immediately take a measurement of the clay height and record it on the data sheet. Have students record the number of books (in this case, two) and the total weight of the books. Have students repeat this process with the clay crumbles or falls over, or they run out of books. Remind students to make sure they use the same books from the previous measurement when adding more books.

3. Ask the class to explain (using engineering terms of forces, stress and strain) what is happening? (Answer: The books place a compressive force on the clay. As more books are added, the clay cannot support the increasing weight and the clay compresses. The force on the top of the clay creates a strain in the clay and therefore stress as well.)

4. Have students fill in the change in height (original height - new height), strain (change in original length), and stress (weight + area) on the data sheet table, as shown in the example at the top of the table.

5. Next, have students graph a displacement vs. load curve on the data sheet. Plot the weight of the books on the horizontal axis and the displacement on the vertical axis. Point out how we plot the independent variable on the horizontal axis and the dependent variable on the axis. In this case, the displacement is dependent on the weight of the books. What do the graphs show us? Compare graphs from different teams. Invite student comments.

6. Next, have students graph a stress vs. strain curve on the data sheet. Plot stress on the vertical axis and strain on the horizontal axis. Using this graph, have students calculate the slope in a linear (flat) portion of their graph. The slope can be found by selecting two points on the graph. Calculate the change in stress between these two points (the rise). Calculate the change in strain between these two points (the run). Then divide the change in stress by the change in strain (rise over run). This value is the modulus of elasticity for the clay sample. Compare graph modulus of elasticity calculations from different teams. What do the graphs show us? Invite student comments.

7. Have students compare their graphs to the graph provided on the last page of the data sheet. They should compare their modulus of elasticity for the clay sample to that provided for steel and concrete. When...
clay, steel and concrete, what have we learned? The modulus of elasticity indicates the 
of a material; how does clay compare to steel and concrete?

8. To conclude, lead a class discussion comparing results and conclusions. Ask the class 
activity questions provided in the Assessment section.

Attachments (Return to Contents)
- Materials Data Sheet (doc)
- Materials Data Sheet (pdf)
- Materials Data Sheet Answer Example (doc)
- Materials Data Sheet Answer Example (pdf)

Troubleshooting Tips (Return to Contents)
When placing the books on top of the clay, first use the lightest books, followed by the heavier 
books. Have at least 10 lbs (4.5 kg) of books available to use per team. The clay usually starts to comp 
act the clay after 1.5 pounds (.68 kg), depending on the clay.

When selecting the two points for calculating the slope of the line, make sure students choose p 
points separated by at least two other points. Choosing points adjacent to each other may yield err 
values.

If the cross-sectional area of the clay piece is not equal to 1 in² (6.35 cm²) with 1 inch x 1 inch (; 
2.5 cm) dimensions, revise the area of clay column of the table on the data sheet with the actua

Assessment (Return to Contents)
Pre-Activity Assessment
Prediction: Have students predict the outcome of the activity before the activity is performe 
students to predict whether there are similarities between the strength of steel, concrete an

Activity Embedded Assessment
Data Sheet/Pairs Check: Use the attached Materials Data Sheet to help students follow alo 
activity. After students finish the worksheet, have them compare answers with a peer or an 
giving all students time to finish the worksheet. Review their answers to gauge their master 
concepts.

Post-Activity Assessment
Prediction Analysis: Have students compare their initial predictions with their test results, as 
on the worksheets.

Question/Answer: Pose the following questions to the entire class or individually as homew 
- When creating graphs from collected data, the independent variable goes on which axi 
  graph? The dependent variable? (Answer: The independent variable always goes on t 
horizontal axis [x-axis] and the dependent variable always goes on the vertical axis [y-"
- Based on your observations, is the clay a brittle material or a ductile material? (Answer 
  behaves as a ductile material when it is moist. Recall how the clay yielded some before 
over, or deflected a lot before complete failure)
- If the clay were to be completely dried out, making it look and feel like a rock, would the 
  brittle material or a ductile material? (Answer: If completely dried out, the clay would be 
brittle material. In this case, we would observe the clay easily crack or chip when a forc 
  applied.)
- Based on the curves in the graph on the last page of the data sheet, is steel a brittle 
  ductile material? (Answer: Steel is a ductile material. We can tell from its stress vs. stra 
that steel yields before it fractures.)
- Based on the curves in the graph on the last page of the data sheet, is concrete a brittle 
or a ductile material? (Answer: Concrete is generally considered a brittle material. We 
from its stress vs. strain curve that concrete might yield some before it fractures but vei 
Why is it important for engineers to be able to quantify (measure) the strength of mater 
(Answer: Use this open-ended question to encourage students to think about the stren 
materials. In general, engineers want to know the properties of the material in advance 
them in a bridge so they can design the structure to be strong enough to stay safe [not 
its anticipated forces and stresses.)
Activity Extensions

Perform the test on a dried-out piece of clay and compare the difference between a brittle (dry) and non-brittle (moist clay) material by comparing the graphs and calculations.

Arrange to visit a local university's materials testing lab or ask engineering students or professors to bring examples of tested materials for "show and tell" in your classroom. Ask if the university tests steel, concrete, wood, plastics and/or composite materials.

Arrange for a tour at your local cement plant. Find out all the different mixes of concrete they make, and for what specific applications.

Activity Scaling

- For lower grades, complete the data sheet together, as a class.
- For upper grades, have students prepare a short presentation on their findings. Using all of the values obtained for the modulus of elasticity (E), calculate the class average.

Additional Multimedia Support


References

ACI Committee 318, Building Code Requirements for Structural Concrete (ACI 318-02) and Commentary (ACI 318R-02): An ACI Standard, American Concrete Institute, Farmington Hills, MI, 2002.


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