Theme 1: Structure and Process

Introduction:

Materials like concrete and steel are important components of highway construction, but so are management tools such as planning and scheduling. This theme, Structure and Process, attempts to integrate these components using the construction of a highway overpass as an example. Activities should be done in the order presented. The concrete made in Activity 1 will need two days to cure before being tested in Activity 4.

Objectives:

- Use Gantt charts to manage a project efficiently.
- Experiment with ABC (Accelerated Bridge Construction) methods to minimize the impacts of construction.
- Design and build a reinforced concrete deck slab.
- Create and apply test plans for evaluating designs and processes.

Standards:

- MS-ETS1-2 Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem. https://www.nextgenscience.org/pe/ms-ets1-2-engineering-design
- MS-ETS1-3 Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success. https://www.nextgenscience.org/pe/ms-ets1-3-engineering-design
- MS-ETS1-4 Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved. https://www.nextgenscience.org/pe/ms-ets1-4-engineering-design

Activity 1: Build it Strong!

Objective:

- Design and build a reinforced concrete deck slab.

Background Information:

Concrete is the most common construction material for large structures. Concrete is made from three materials:

- Aggregate: Sand and gravel
- Cement: A chemical glue that holds the aggregate together with great strength
- Water: Not only does water help with mixing and pouring concrete, it bonds with the cement in a chemical reaction, becoming a part of the finished concrete.

Bridge decks must carry the weight of all the cars and trucks that might be traveling across them. Different parts of the bridge deck experience different types of forces. Compression is a squeezing, or crushing force. Tension is a pulling, or stretching force.

To help them hold both types of forces, bridge decks are made from steel-reinforced concrete. Concrete can handle compression very well, but tension causes cracks quickly.

Steel is excellent at resisting tension. Together, concrete and steel can handle both types of forces that happen on a heavily loaded bridge deck.

Reinforced concrete is made by pouring concrete onto a mesh of steel bars, called rebar. In this activity, students will make reinforced concrete deck slabs using sand (the aggregate), plaster of Paris (the cement), water, and paperclips (as rebar). In the final activity of this unit, after their concrete has cured, they will test the strength of their deck slabs to evaluate their rebar designs.

Materials for a class of 24:

- 16 plastic cups (12-oz or larger)
- 2+ ¼-cup measuring cup (having several will speed-up the activity)
- A 4-lb box or tub of dry-mix Plaster of Paris (will be enough for two classes)
- A 0.5 ft^3 bag of sand. This will be enough for all of your classes. Keep the leftover sand, as you will need it for Activity 4.
- 2 or 3 gallons of water in pitchers or plastic jugs (your sink will be off-limits today)
- 8 craft sticks or something similar for stirring
- 1 box of 100 small paper clips
- 1 roll of paper towels
- 1 trash can with plastic liner for throwing away wet waste (your sink will be off-limits today)
- 1 roll of aluminum foil (each class will use about four feet)
- 2+ roll of masking or cellophane tape (having several will speed-up the activity)
- 4 printed pages of “Deck Slab” Forms
- 4+ pairs of scissors (having more will speed-up the activity)
- 8 pieces of cardboard, or cafeteria trays, or something that students can use to move their still-drying concrete from where they poured it to where it can sit undisturbed for a few days.

Advanced Preparation:

- Print student pages.
- Print (single sided) four sheets of “Deck Slab” Forms.
- If you have a sink in your room, make a “No sink today!” sign. If you can, cover your sink with something and hang your sign. Plaster can easily clog drains.
- For each group, pre-measure ½ cup of Plaster of Paris into a plastic cup. **Don’t let students get their hands on the whole container of plaster.**

Implementation:

Show students the slides of construction workers pouring concrete onto rebar. Let them explain or guess what is happening and why.

Show the slides of a highway overpass so they can see it is constructed of reinforced concrete slabs.

Explain that students will be working in groups to create their own reinforced concrete slabs.

Explain the following **safety issues**:

- Students must wear goggles, masks, and gloves when mixing their concrete.
- Gloves will protect the skin from irritation, but not from the heat produced by the chemical reaction of plaster and water. **Don’t put your fingers in the wet concrete!**
- All waste, including liquid, goes into the trash can, **not** the sink.

Pass out the student pages and let students work through the instructions.

Debrief Questions:

- Why do you think rebar is used in making concrete slabs?
- How did you choose to arrange your rebar?
- Why do you think that arrangement will make a strong bridge?

Extensions:

You can also have students do this activity using real concrete. Just substitute Portland cement for Plaster of Paris. You can find Portland cement in hardware stores like Lowes or Home Depot. All the same safety rules apply, but you must be extra careful that students are following those rules. Portland cement is caustic and more likely to irritate skin than is Plaster of Paris. It is also more likely to clog drains or damage floors and counters if it is not cleaned up promptly. Keep a canister of wet wipes on hand so students can clean spills easily. Make sure students wear goggles.

Career Connections:

- Construction Laborer
- Structural Iron and Steel Workers
- Materials Engineer
- Civil Engineering Technologists and Technicians

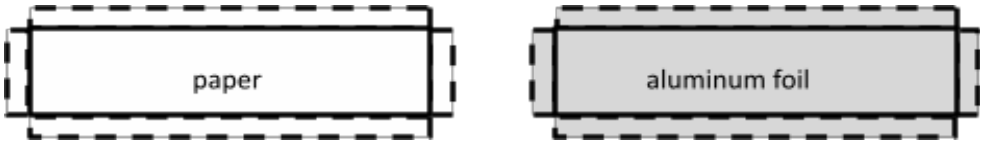
Build it Strong! – Student Handout

Highway bridges usually have a deck (the part you drive on) built from slabs of reinforced concrete. The concrete is a mixture of sand, cement, and water. The reinforcement comes from steel bars around which the concrete is poured. All of this is held within a mold, called a form, to give the finished slab the desired size and shape. Today, you will make a reinforced concrete deck slab. In a few days you will test its strength.

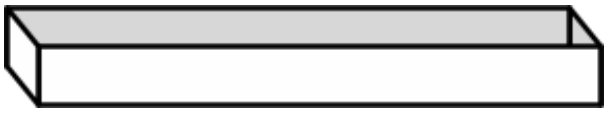
Problem: How can steel reinforcement bars (called rebar) be used to make concrete strong, but not too expensive?

Procedure:

1. Form a group of three.
2. Get a sheet of Deck Slab Forms. Using scissors, cut out one deck slab, but don't fold it yet.
3. Place the unfolded Deck Slab Form onto a piece of aluminum foil and use a marker or pen to trace the online of the form onto the foil.
4. Cut out the foil so you have a paper form and a foil form of the same shape.



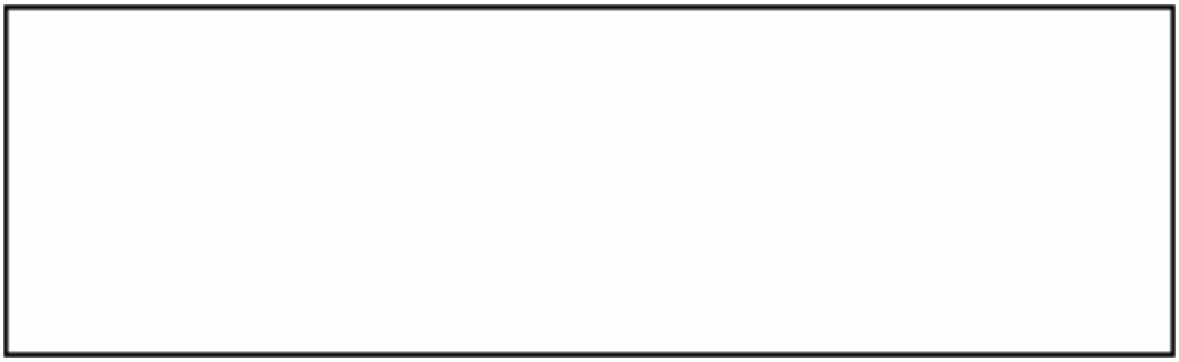
5. Fold the paper form into an open box shape and tape the corners to hold them in place.



6. Put the foil shape into the paper form to act as a liner. Try to keep the bottom smooth. The wet concrete will not stick to foil the way it would to paper.
7. Place this form onto a tray or piece of cardboard (something provided by your teacher) to protect your table from leaking concrete. After pouring, you will probably be moving this tray to a safer area so it can dry for several days without being disturbed.
8. Get some paper clips to act as your rebar. Use at least five, but no more than ten.

Steel is expensive, so it would be best not to use more than you need. Your goal is to create a concrete deck slab that can support the weight of 15 cups of sand.

9. Soon, you will place these into the form and pour concrete over them. Discuss how you could bend and arrange the paper clips to give the most strength to your deck slab. Place your rebar into the form as desired and sketch your design in the space below. Record the number of paperclips used: _____



10. Have your teacher approve your setup and give you the OK before proceeding.
11. Everyone put on goggles, gloves, and a mask. It's time to make concrete!
12. Split up to get the following materials:
    - A plastic cup containing a pre-measured amount of cement that was prepared by your teacher
    - An empty plastic cup into which you add ¼ cup of cold water
    - An empty plastic cup into which you add ¼ cup of sand
    - A stirring stick
13. Gently begin sprinkling the cement into the cup of water, without stirring. Go slowly.
14. You may feel the cup of water getting warm. This heat is from the chemical reaction. **Do not put your fingers in the cup.**
15. After all the cement has been added, use your stick to SLOWLY stir the mixture. Stirring too quickly will create air bubbles that make your concrete weaker.
16. Begin to SLOWLY add the sand to your mixture. Keep stirring SLOWLY.
17. Gently pour your concrete into the form. Do it carefully, trying not to move your rebar. Pour until you reach the top, but don't overflow the form. If you have extra concrete, leave it in the cup.
18. Place your trash, including any leftover concrete, into the trash can, **not** the sink.

Activity 2: The PB&J Project

Objective:

- Use Gantt charts to manage a project efficiently.

Background Information:

Complex projects, such as bridge construction, require thoughtful planning. Project Management is the discipline of planning and controlling the work of a team to reach a specific goal. Successful Project Management requires a careful consideration of deadlines, budgets, and available resources.

The Gantt chart is a project management tool that shows tasks in terms of their time-to-complete, interdependency, and available resources. Developed by American engineer Henry Gantt, these charts were first employed in shipbuilding, the construction of the Hoover Dam, and the Interstate Highway System.

Today they are used for all manner of project management tasks. Computers have made the Gantt chart simple to create and easy to update.

Materials for a class of 24:

- 8 sets of “PB&J” cards (1 set per group)
- 8 pairs of scissors (1 per group)
- 8 sheets of colored paper (1 per group)
- Cellophane tape (at least 1 roll per class)

Advanced Preparation:

- Print and cut-out “PB&J” cards

Implementation:

Begin by asking students:

- Have you ever eaten a PB&J (peanut butter and jelly) sandwich?
- Have you ever made a PB&J sandwich?
- How long would it take to make one? Record some guesses on the board.

If you suspect that your students might be unfamiliar, have the actual materials on-hand to demonstrate making a PB&J while you talk. If peanut allergies are a concern, almond butter and cashew butter can be used instead.

Pass out Student Pages and have volunteers read the background information and problem statement.

Help students form groups. Three per group is ideal, but 2-4 will work.

Distribute the materials.

Explain that this task will require about two meters of clear space on a tabletop or floor. Encourage students to clear this space before they begin laying down the task cards.

Allow students to go through the activity as written in their Student Pages. Circulate and check their work frequently. Look for logic flaws, such as spreading jelly before the jelly jar has been opened.

Encourage thought with challenging statements such as:

- Do you really think that is the best way to do it?
- Could you do it differently?

At one point, allow a student to facilitate a discussion to help the class reach consensus on how long it takes to complete each task.

If you want to foster friendly competition, encourage groups to put their total times on the board. This is a challenge for others to find a faster way.

When students have completed the last part of the activity, have them circulate, looking at what other groups have done to solve the same problem.

Debrief Questions:

- Was there more than one way to organize the tasks?
- Did the addition of a second person allow you to complete the project in half the time it took one person? Explain?
- What techniques did you use to minimize the time needed to complete the sandwich?
- How did the addition of a second knife change things?
- How quickly could the sandwich be made if 10 people were available to help?

Extensions:

1. As groups implement changes that reduce the total time, have them calculate percent reductions to quantify their improvements.

$$Percent\ reduction = \frac{Original\ time - new\ time}{Original\ time} \times 100\%$$

   This is a skill in 6th-grade math standards, but students can always use practice with percent calculations.

2. Free software for making Gantt charts is available online. It will take a bit of time for students to learn how to use it, but this is time well-spent. Students can begin by using it to diagram their PB&J project.

   Ganttproject is a good option. It is a free download, and students are not asked to register or provide any personal information.

Career Connections:

- Urban and Regional Planner
- Industrial Engineer, Technologist, or Technician
- Production, Planning, and Expediting Clerk
- Meeting, Convention, and Event Planner
- Logistician

The PB&J Project – Student Handout

Complex projects, such as highway construction, require thoughtful planning. **Project Management** is the discipline of planning and controlling the work of a team to reach a specific goal. Successful Project Management requires a careful consideration of deadlines, budgets, and available resources.

Problem: Apply basic principles of Project Management to plan the construction of a delicious peanut butter and jelly sandwich (PB&J).

Procedure:

1. Find two partners and clear a space to work. Five feet of space, left to right, would be ideal.

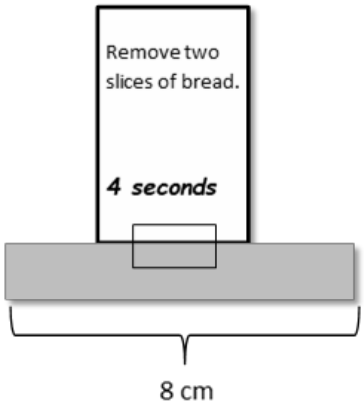
2. Once your teacher gives you the cards, spread them out so you can read them all. Each represents one task involved in making a PB&J sandwich.

3. Starting from the left, and proceeding to the right, arrange the tasks in the proper sequence from the first step to the last.

4. Is there more than one “proper” sequence? Explain below.

5. Consider how long it takes to do each task. Assume you are not in a rush, but want to make an excellent PB&J sandwich. Act it out and count how many seconds it takes. As a class, decide on a reasonable time for each task. Write the number of seconds for each task on the appropriate card.

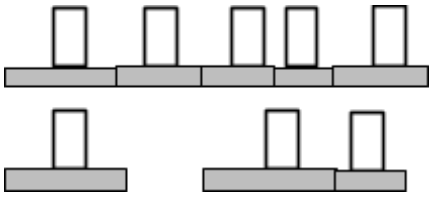
6. To physically represent the time required for each task, you will attach a strip of colored paper to each card. The length of the strip will represent the time required to complete the task. Use a scale of 2 cm equals 1 second. Begin by measuring and cutting the strip to the correct length. Then tape the strip below the card as shown below.



7. After attaching paper strips to each card, place the tasks in sequence again. When you are finished, there should be a continuous line of paper strips, progressing from left to right.

8. What is the total time it would take to complete the sandwich? _____

Now imagine that you have a helper, a second person who can assist in making the PB&J sandwich. No other additional materials are available, just a second set of hands to help make the sandwich faster. Since some of the tasks may now be performed simultaneously, you make two lines, one above the other. Each line represents what one person is doing. There may be gaps in the lines if one person is waiting on another to perform a task.



9. Try to arrange the tasks in a way which allows the sandwich to be completed as rapidly as possible.

   Now how long does it take? _____

   If another group claims to have found a faster way, examine their plan and verify that their plan makes sense.

10. Now suppose that the second person helping you make the sandwich also has their own knife. Rearrange your tasks again.

    With two knives available, how quickly can you make the sandwich? _____

Activity 3: Build it Fast!

Objective:

- Experiment with Accelerated Bridge Construction (ABC) methods to minimize the impacts of construction.

Background Information:

One of the costs of any road project is the economic impact of rerouting traffic during the construction. Methods that minimize the disruption will reduce costs and often improve safety. Accelerated Bridge Construction (ABC) methods include prefabricating as much of the bridge as possible at an off-site location. Large parts are brought to the site and installed according to a plan that minimizes the time required to reroute traffic.

Materials for a class of 24:

- 48 large marshmallows (6 per group). You will need another 24 marshmallows for Activity 4, if you want to buy them all at once.
- 8+ pairs of scissors (1+ pair per group)
- 8 copies of "Example Overpass" (1 copy per group, print single sided)
- 16 index cards (2 per group)
- 8+ rulers (1+ per group)
- 1 classroom clock that displays seconds, or project from a website like https://www.timeanddate.com/timer/ or stopwatches or smart phones

Advanced Preparation:

Print the "Example Overpass" pages single sided. You can use regular copy paper, but heavier paper or cardstock is even better.

Implementation:

Begin by showing a time-lapse video of the construction of a highway overpass such as this: https://www.youtube.com/watch?v=fMMY0sV6_Ak

Or this: https://www.youtube.com/watch?v=AHtf4QnZ9E0

Allow students to make observations and ask questions about what they see.

Help students form groups of three. Give them handouts, paper, and scissors. Instruct students not to eat the marshmallows, and then distribute the marshmallows.

Show them the slideshow of the "Example Overpass". Allow them to work through their student handout.

It is *not* important that their overpass look exactly like the example. Anything close should work for now.

After students test the example plan, allow a student to facilitate a whole-class discussion to decide how the time measurements can be used to "score" the new plans that each group will develop. In addition to meeting your NGSS engineering standards, this will allow students to compete to develop and execute the best possible plan.

Debrief Questions:

- What types of changes resulted in a better construction plan?
- You were only measuring speed. Are there other factors that a real team should consider when planning a big construction project?
  Possible prompts: cost, safety, environmental impact, social impact

Extensions:

1. As groups implement changes that reduce the lane closure times, have them calculate percent reductions to quantify their improvements.

$$Percent\ reduction = \frac{Original\ time - new\ time}{Original\ time} \times 100\%$$

   This is a skill in 6th grade math standards, but students can always use practice with percent calculations.

2. Have students make Gantt charts of their plan. One option is to use paper strips as was done in a previous activity of this unit. Another option is to do it on a computer. Free software for making Gantt charts is available online. It will take a bit of time for students to learn how to use it, but this is time well-spent. Students can begin by using it to diagram their overpass construction plan.

   Ganttproject is a good option. It is a free download, and students are not asked to register or provide any personal information.

Career Connections:

- Construction Manager
- Operating Engineers and other Construction Equipment Operators
- Highway Maintenance Worker

Build it Fast! – Student Handout

An overpass is a bridge that takes one road over the top of another. Building an overpass requires temporarily closing the road beneath it. That closure causes traffic delays and disruption to the community. Engineers and planners look for ways to complete the construction quickly to keep the closures as short as possible.

Problem: Identify and test improvements to a plan for building an overpass.

Procedure:

Using index cards, make a pair of signs. Write “CAUTION” on the front of each card and “DETOUR” on the back of each card.

Assign roles within your group.

1) One person does all of the cutting and folding.
2) One person places all the finished parts in their proper locations.
3) The manager reads the instructions to others and records times.

If you have only two people, one of you can do both the 2nd and 3rd roles. A fourth person could help with the 1st role.

Build your Example Overpass using the following instructions:

1. Place a CAUTION sign next to each set of lanes. (Record the time.)
2. Place six piers (marshmallows) on the ground as shown in the diagram.
3. Build Beam #1.
4. Close the eastbound lanes by flipping the sign from CAUTION to DETOUR. (Record the time)
5. Place Beam #1 across the eastbound lanes.
6. Build Beam #2.
7. Place Beam #2 across the eastbound lanes.
8. Build Beam #3.
9. Close the westbound lanes by flipping the sign from CAUTION to DETOUR. (Record the time)
10. Place Beam #3 across the westbound lanes.
11. Build Beam #4.
12. Place Beam #4 across the westbound lanes.
13. Create four deck slabs.

14. Place Deck #1 and Deck #2 onto Beams 1 and 2, above the eastbound lanes.
15. Reopen the eastbound lanes by flipping the sign to CAUTION. (Record the time)
16. Place Deck #3 and Deck #4 onto Beams 3 and 4, above the westbound lanes.
17. Reopen the westbound lanes by flipping the sign to CAUTION. (Record the time)

For how long were the eastbound lanes closed? _____

For how long were the westbound lanes closed? _____

For how long were both lanes closed at the same time? _____

How long did the entire process take? _____

That took too long! You can do better. Create a new plan.

As a class, decide how you will use time measurements to judge the effectiveness of your new and improved construction plans.

As a group, create a new plan to build the same bridge. Start from scratch with new paper. You may assign any task to any person. Tasks may be done in any order. If your teacher allows, you might be able to use an additional ruler or pair of scissors.

Once you are ready, begin the construction, being careful to record times when lanes open and close.

Compare your plan and results with those from other groups. Look for ideas that others had which might improve your own plan.

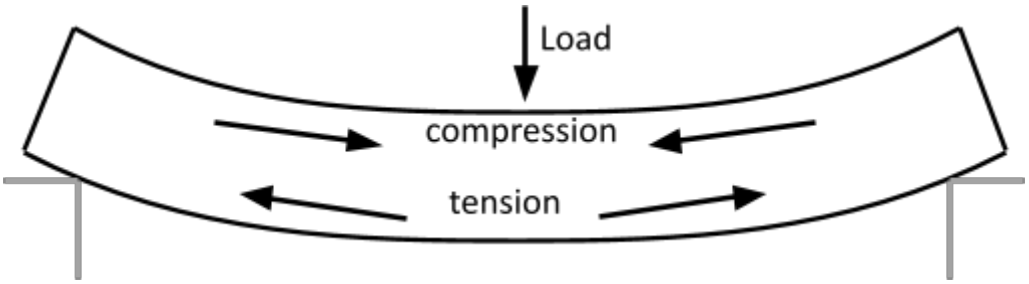
Activity 4: Testing Student-made Concrete Decks

Objective:

- Create and apply test plans for evaluating designs and processes.

Background Information:

When a structural beam is loaded from above, the force creates compression on the upper surface and tension on the lower surface. Concrete can withstand ten times as much compression as it can tension. Since concrete is much less capable of supporting tension, it is along the bottom that steel reinforcement is most important.



In this activity, students will perform a 3-point load test to see how much weight their slabs can hold.

Materials for a class of 24:

- The reinforced concrete slabs the students made in Activity 1
- 24 large marshmallows
- 3 feet of string or twine
- 15 plastic sandwich bags with zip enclosure

Advanced Preparation:

- Print student handouts
- Make 15 sandbags by putting 1 cup of sand into each plastic sandwich bag.

Implementation:

Begin by showing the slides of bridges with visible cracks. Only the last bridge would be considered a failure by engineering definitions, but let your students decide. Facilitate the discussion until they have a one sentence definition of “failure” for a bridge.

Continue with the slides to arrive at a step-by-step test procedure that can be applied to rank the performance of each slab. Recall that the cost of each slab depends on how much rebar was used in its construction.

Pass out the student handouts and marshmallows. Explain that these are not for eating. Allow students to complete their handouts.

Now conduct your testing, using the procedure created by your students.

As each team is subjecting their slab to the test, have one member of that team reveal their rebar design, including the number of paperclips used, to the class.

After all tests have been performed, have students rank the bridges in order of their performance.

Debrief Questions:

Have each team explain what aspects of other groups' designs might improve the performance of their own.

Extensions:

Make new slabs using the lessons learned, and measure their performance.

Career Connections:

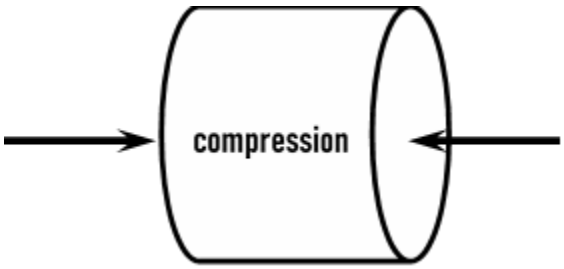
- Mechanical Engineer
- Civil Engineer
- Construction and Building Inspectors
- Occupational Health and Safety Technician

Testing Your "Concrete" Deck – Student Handout

Problem: Which slab of reinforced concrete has the best performance? In this activity, the best performance means holding 15 cups of sand without failure, using the least amount of rebar. What if none can hold up to15 cups of sand? Then, which is the best?

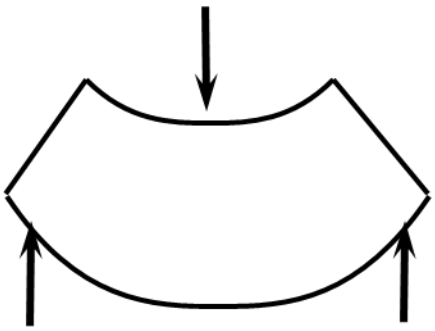
Procedure:

Your teacher will give you a marshmallow. Don't eat it. Gently, apply a bit of squeezing force as shown below. This creates compression in the marshmallow.



Gently apply a bit of pulling force. This creates tension in the marshmallow.

Gently bend the marshmallow as shown in the diagram below.



Which part of the marshmallow is in compression? Label it on the diagram above.

Which part of the marshmallow is in tension? Label it on the diagram above.

Concrete is very good at resisting compression, but tends to crack when placed in tension. Rebar is added because it resists tension very well. When you test your slab, will you want the side with more rebar to be the upper surface or the bottom surface? Explain.

Now is the time to test your slabs. Record your data below:

Group #	cups of sand before failure	observations on failure	amount of rebar	arrangement of the rebar

What design seemed to be best?

How would you modify your design to improve performance?