Berkeley Engineers and Mentors

BEAM the Builder

Minji Lee | Spring 2022

Field(s) of Interest: Civil Engineering, Materials Science, Physics

Brief Overview (1-3 sentences):
In this lesson, mentees will learn about the basic structural elements of a building – slab, beam, column – and how load and stress affect these elements. Using this knowledge, mentees will then construct their own building with their choice of materials.

Agenda:
- Introduction (5 min)
- Module 1: BEAM is key!
- Module 2: Stressed BEAMers
- Module 3: BEAM the builder, yes we can!
- Conclusion (5 min)

Main Teaching Goals/Key Terms:	Mentor Development Goals:

➔ A **load** is the force applied on a surface or a structure.
➔ **Stress** is the force acting on the unit per area of the material.
    ◆ **Tension** is a pulling force applied on the material.
    ◆ **Compression** is a pushing force applied on the material.
➔ The **engineering design process** is the process of trial and error and repeatedly testing and improving upon models.
	➔ **It's not copy-and-paste!**
	➔ **A blueprint for teaching?**
	➔ **Just fancier trial and error…**

Mentor Development Notes

Written by Ryan Dai

It's not copy-and-paste!

The abundant choices of materials to serve a multitude of structural purposes is a great reminder to both mentors and mentees that there is **not an absolute right answer** to the question *What is the best building material?*, or more generally, *What is the best engineering solution?* Mentors are encouraged to challenge mentees in Module 2 **why and how** a particular material suits their building needs in Module 3. Mentors should also be prepared to support mentees' curious and imaginative choices; for example, a rubber band may not be as good as popsicles in compression, however, suspension cables are analogously the vital tensive element of the Golden Gate Bridge!

TLDR: be open-minded and encourage mentees' imagination in solving engineering problems!

A blueprint for teaching?

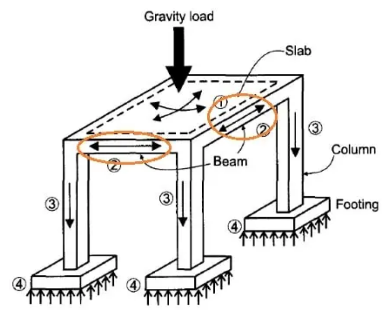
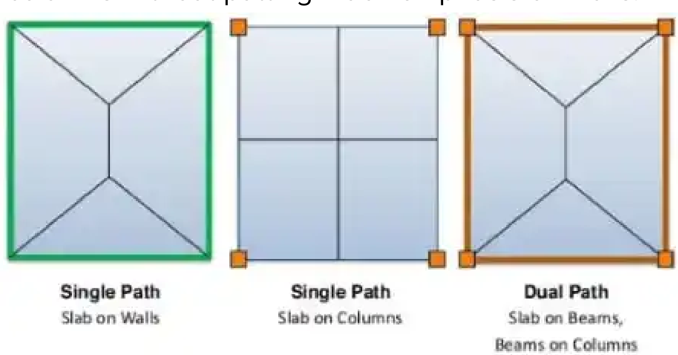
This lesson features a very open-ended activity in Module 3 and mentors may find it difficult to plan and prepare for such a module. This problem may be amplified for virtual sites as remote classroom control may have been frustrating even for the most structured lessons. This is a great opportunity for mentors to practice the art of asking **guiding questions**! Mentors are encouraged to prepare a list of questions to ask mentees throughout their design process! From drawing their blueprints to building their structures, be sure to ask mentees (1) what are their **thought processes**? (2) what are the goals they are trying to **achieve**? (3) if they fail, how will they **improve**? Be specific with your questions and guide them toward their goals!

Just fancier trial and error...

If you have not already realized, this lesson involves a lot of trial and error, which reflects the general nature of engineering and design work in real life! There is a specific teaching goal that is aimed at this approach and is repeated throughout the lesson: Engineering Design Process. While it may seem straightforward to simply try until you succeed, the most important aspect of the engineering design process is to **actively reflect on errors** and **what can work better** to foster improvement in the next trial. It is also important to convey the message that **failure is a part of the process** and should not be a deterrence!

Fun fact: this teaching goal used to be in every BEAM lesson! So don't hesitate to reiterate this many times at site!

Background for Mentors

Module 1 ● Loab ● Slab ● Beam ● Column	A **load** is the force applied on a surface or a structure; for buildings, this is often from the weight of the building itself and other objects. Such load is dispersed through the entire building through numerous structural elements. The **slab** is a horizontal structural element that is used to create flat and useful surfaces such as the floor. The load is horizontally transferred throughout the slab to its supporting element such as the beam, column, or wall. The **beam** is another horizontal element that is used to provide a safe and efficient load path that effectively distributes the load from the slab throughout the whole building. Similar to the slab, the load in a beam is also transferred horizontally to attached columns. The **column** is a vertical structural element where the load is transferred vertically. This is the most crucial structural element as a failure in the column (ex. Cracks, deformation) will cause the whole building to collapse.  **Fig 1.** *Transfer of load in slab, beam, and column* Lastly, some buildings use walls instead of beams and columns in order to reduce costs. Here, the load is transferred directly from the slab to the wall. However, these buildings are less resistant to earthquakes compared to buildings using beams and columns. In this lesson, we will focus on slabs, beams, and columns without putting much emphasis on walls.  **Fig 2.** *Transfer of load different building systems*

Module 2

- Stress
- Tension
- Compression
- Bending
- Properties of Materials

Stress is the force acting on the unit per area of the material. Structural elements of a building primarily undergo two types of stress: tension and compression. **Tension** is a pulling force applied on the material while **compression** is a pushing force applied on the material. Different **properties of materials** allow the structural elements of a building to withstand different types of stress.

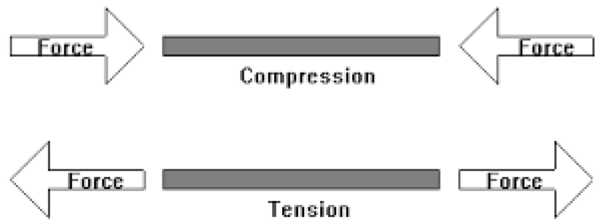


Figure 3. *Compression vs. Tension*

Columns experience **compression** as the load from the beam or slab pushes downwards and its supporting strength pushes upwards. When the column (or other materials subject to compression) breaks due to compression, it is called *buckling*. To prevent a column from breaking, or buckling, it should be made of materials with *high compressive strength* and *toughness*. Examples of materials used in columns are stone, brick, concrete, and steel.

On the other hand, slabs and beams experience both **tension** and **compression**. Here, the top of the structural element undergoes compression due to the applied load while the bottom undergoes tension and results in **bending**. To prevent a beam or slab from bending, it should be made of materials with *high tensile strength* and *stiffness*. Examples of materials used for beams are concrete, steel, and wood; slabs are often made of concrete.

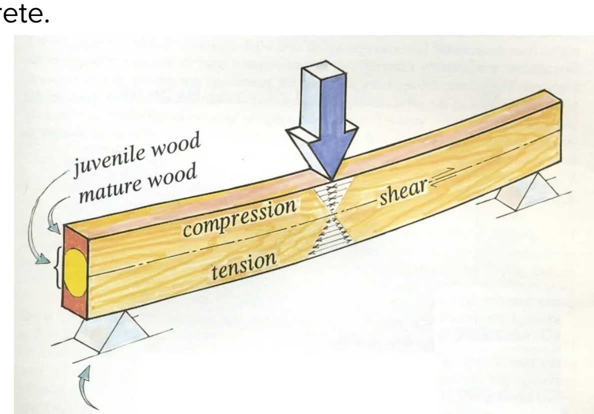
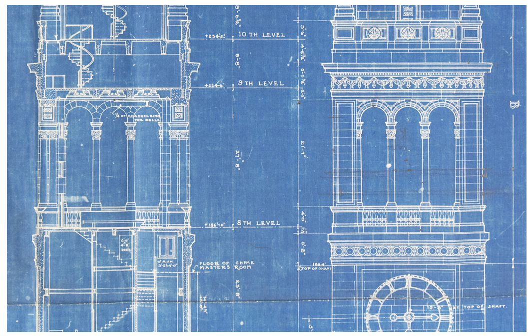
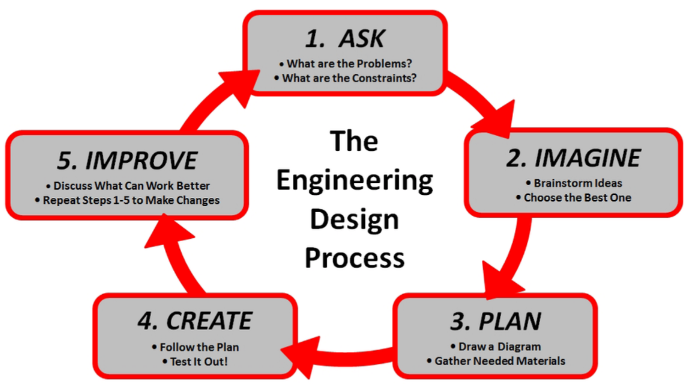


Figure 4. *Bending in a Beam (Tension + Compression)*

Module 3 ● Construction Plan ● Engineering Design Process	Before constructing a building, engineers and architects usually draw and plan their design using a **blueprint** or floor plan. **Blueprints** refer to a reproduction of technical drawings using a contact print process on light-sensitive paper; however, this process has now been replaced by photocopiers and the term is now used to refer to floor plans or construction-related drawings. Blueprints include details such as the dimensions of the building, individual floor plans, and descriptions of all materials used.  **Fig 5.** *Blueprint of Campanile at UC Berkeley* In industry, engineers construct buildings after ensuring that a building can withstand a certain amount of load. However, in this module, the mentees will be constructing buildings using the **engineering design process** where they will go through a process of trial and error in order to make a building that can withstand the given load. The engineering design process is split up into 5 main steps: ask, imagine, plan, create, and improve. If the mentees' initial building design does not work, encourage them to continue improving their design based on the issues they observed.  **Figure 6.** *Engineering Design Process*

Introduction

Concepts to Introduce	**Current or Past Events**

• Civil Engineering vs. Architecture
    ○ Both fields are focused on building various structures.
    ○ Civil engineering is more focused on infrastructure (ex. highways, dams, buildings) and their functionality and structural stability.
    ○ Architecture is more focused on the design of buildings and its aesthetic aspects.
• Steel is a metal mixture (iron + carbon) that is often used in buildings because it is light, long-lasting, and stronger relative to other metals such as iron.
	• Tower of Pisa
	    ○ This tower in Italy starting leaning after 5 years of construction due to its poor foundation (structural element not covered in this lesson)
	• Home Insurance Building, Chicago
	    ○ This was the first skyscraper that used a steel frame (steel beam and columns)
	• Golden Gate Bridge
	    ○ This bridge is a suspension bridge that uses tension from the cables to hold itself up.

Questions to Pique Interest	**Inspiring Scientists, Careers, Applications**

• What is the most important part of a building?
    ○ What steps should you take when you are designing a building?
• What materials do you need to build a building?
    ○ Can you improve or strengthen any of these materials?
	• Civil Engineer
	    ○ Concentrate on the structural elements of the building and ensure that structure can endure all conditions
	• Architect
	    ○ Focus more on the spatial functionality and aesthetics of the building
	• Material Scientist or Engineer
	    ○ Develop highly functional materials that can increase the structural integrity of the building (ex. steel)

Module 1: BEAM is key!

In this module, mentees will be introduced to the basic structural elements of a building: slab, beam, and column. They will also learn about load and how load travels through each structural element through a demo with 3 types of buildings that use different structural elements.

Teaching Goals	**Materials (per site)**
1. A **load** is the force applied on a surface or a structure. 2. A **slab** is a horizontal structural element used to create flat surfaces (ex. Floor, ceiling) 3. A **beam** is a horizontal structural element used to distribute the applied load throughout the building. 4. A **column** is a vertical structural element used to carry the load from the slab or the beam.	Building 1 ● 1 index card (slab) ● 4 toothpicks (column) ● 8 ½ styrofoam balls ● 5 popsicle sticks (beam) Building 2 ● 1 index card (slab) ● 4 toothpicks (column) ● 8 ½ styrofoam balls Building 3 ● 3 full index cards (1 slab, 2 walls) ● 2 smaller index cards (2 walls) Per site ● 1 paper cup ● 30 pennies (weight) ● 1 roll of tape

Procedure

1. Split mentees into 3 or 6 groups depending on the amount of materials given. One group will be in charge of building one type of building.
2. Building 1 - slab, beam, column (Fig. 1-1)
    a. Tape the popsicle sticks (beam) to the index card (slab).
    b. Tape 4 ½ styrofoam balls to each corner of the slab.
    c. Place 4 toothpicks (column) on the styrofoam balls. Attach remaining 4 styrofoam balls to the exposed end of the toothpick. The final product should look like Fig. 1-2.
    d. Flip the building over so it looks like

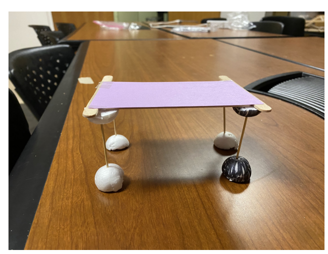


Figure 1-1. *Building 1 (slab, column, beam)*

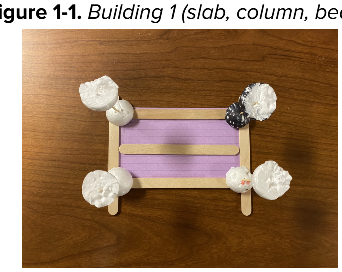


Figure 1-2. *Inside of building 1*

Fig. 1-1.

3. Building 2 - slab, column (Fig. 1-3)
    a. Tape 4 ½ styrofoam balls to each corner of the slab.
    b. Place 4 toothpicks (column) on the styrofoam balls. Attach remaining 4 styrofoam balls to the exposed end of the toothpick. The final product should look like Fig. 1-4.
    c. Flip the building over so it looks like Fig. 1-3.
4. Building 3 - slab, wall (Fig. 1-5)
    a. Tape all 2 full index cards and 2 smaller index cards around 1 full index card.
    b. Carefully fold to make a box-like structure. (Fig. 1-6)
    c. Apply tape ONLY on the top corners of the building. (Fig. 1-5)
5. Place 30 pennies in the paper cup and place it on top of each building. (Fig. 1-6)
    a. Building 1: building will withstand load
    b. Building 2: building will fall
    c. Building 3: building will fall or walls will bend
6. Talk about how load is transferred in building 1.
    a. The load is horizontally dispersed throughout the slab.
    b. The load from the slab travels horizontally through the beam.
    c. The load from the beam travels vertically throughout the column.
    d. Building 1 is most stable as the load from the weight is both horizontally and vertically dispersed throughout the building.
7. Talk about how load is transferred in building 2.
    a. The load from the slab travels vertically through the column.
    b. Ask the mentees how we can improve this building (ex. Adding more columns)

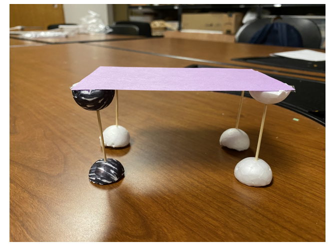


Figure 1-3. *Building 2 (slab, column)*

Figure 1-4. *Inside of building 2*

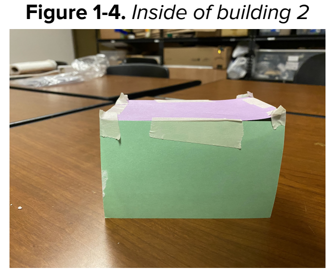


Figure 1-5. *Building 3 (slab, wall)*

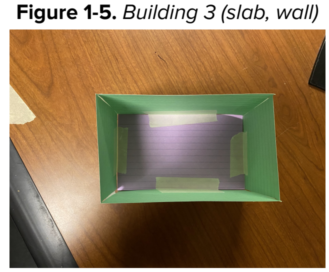


Figure 1-6. *Inside of building 3*

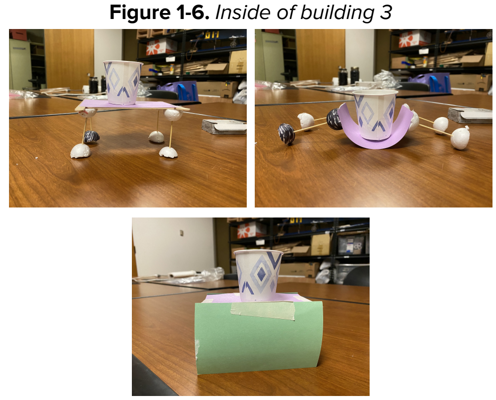


Figure 1-6. *All buildings with applied weight*

8. Talk about how load is transferred in building 3.
    a. The load from the slab will travel vertically through the walls.
    b. If the building falls, ask mentees how we can fix this -> thicker slab

Module 2: Stressed BEAMers

In this module, mentees will learn about different types of stress and how they affect the structural elements of a building. Based on this, they will try to identify which materials should be used for each of the structural elements depending on the materials' properties.

Teaching Goals	Materials (per pair)
1. **Stress** is the force acting on the unit per area of the material. a. **Tension** is a pulling force applied on the material. b. **Compression** is a pushing force applied on the material. c. **Bending** occurs when both types of stress are applied on the material. 2. Different **properties of materials** allow different materials to withstand stress. (ex. Hardness, toughness, ductility)	• 10 popsicle sticks • 20 toothpicks • 3 pipe cleaners • 10 ⅓ (or ½) straws • 5 paper clips • 3 rubber bands • 1 ft yarn • 30 ½ styrofoam balls • 10 index cards

Procedure

1. Discuss what types of stress are applied to each structural element.
    a. Slabs and beams undergo both **tension** and **compression.**
        i. This causes beams to **bend**.
    b. Columns undergo **compression**.
2. Give 1 set of materials to each mentee. Mentees will then try to determine which materials are suitable for each structural element. (ex. Yarn is not suitable for a column because it cannot withstand compression)
3. Discuss why some materials cannot be used for specific structural elements.
    a. Can we engineer these materials to enhance their properties and integrate them into our buildings in Module 3? (ex. Use two toothpicks for a column instead of one)

Module 3: BEAM the builder, yes we can!

In this module, mentees will design and construct their own building. This building should be able to withstand a certain load while satisfying other requirements set by mentors depending on the site. Through this, mentees will be able to apply what they have learned in previous modules while practicing the engineering design process.

Teaching Goals	**Materials (per pair)**
1. A **blueprint** is a drawing that shows a building plan. 2. The **engineering design process** is the process of trial and error and repeatedly testing and improving upon models.	• Set of materials from Module 2 • 1 Paper • 1 Pencil • 1 roll of tape (per site) • 30 pennies (per site) • 1 paper cup (per site)

Procedure

1. Pass out 1 paper and pencil to each mentee. Mentees should draw a blueprint of their building before moving on to the next step. (Fig. 3-1)
    a. These buildings should be free standing, withstand a certain load, and have more than 2 storeys.
    b. There should be a flat surface towards the top of the building. Mentees can choose to include design elements (ex. roof) on top as long as there is a surface to place the load later on.
2. Let mentees build their own building according to their blueprint using the materials from Module 2.
3. When the mentees are ready, start testing the stability of the building using 5 pennies.
    a. After observing the results, allow students to think about how they could improve their structure before testing it with the actual load.
4. When the students are satisfied with their design, apply more pennies to test the maximum load of their building.

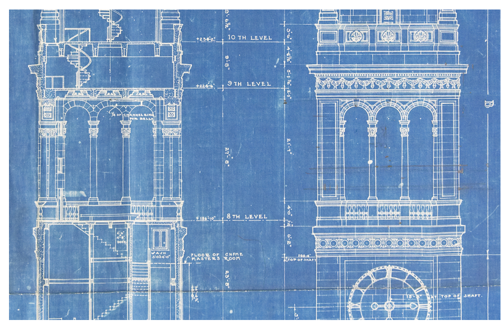


Figure 3-1. *Example of blueprint*

5. For advanced sites, you can add more challenges to make the build more challenging. For example:
    a. Increase minimum number of storeys.
    b. Use all given materials (even things that were eliminated in Module 2)

Classroom Notes

For advanced sites, feel free to add more requirements to the building challenge (ex. Increase minimum height of the building, increase load applied to the building). If time permits, mentees can try to decorate their building by drawing designs on paper and attaching them to the building as “walls”.

Conclusion

In this lesson, mentees had the opportunity to learn about the structural elements of a building. Through demos and activities, they learned the definition of the structural elements – slab, column, beam – and the importance of materials selection. They also practiced the engineering design process as they designed their own building that can withstand a certain load. Ask mentees about some takeaways from this lesson (ex. What was the hardest part of designing your own building? What went well? What can you do to further improve your building?).

References

- 11 of the biggest structural failures in history, Business Insider (https://www.businessinsider.com/biggest-structural-failures-disasters-history-2019-11)
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Summary Materials Table

Material	Amount per Site (30 mentees)	Expected $$	Vendor (or online link)
Styrofoam balls	458 ½ balls per site		Inventory
Toothpicks	308 per site		Inventory
Popsicle Sticks	155 per site		Inventory
Index Cards	158 per site		Inventory
Pipe Cleaner	45 per site		Inventory
Straws	155 per site		Inventory
Paper Clips	75 per site		Inventory
Yarn	15 ft per site		Inventory

Paper (letter size)	15 per site		Inventory
Pencil	15 per site		Inventory
Tape	1 per site		Inventory
Pennies	30 per site		Inventory
Paper Cup	1 per site		Inventory