KSB* 4

(*Knowledge and Skill Builder)

Structural Design

Student Name: ______________________________

Period: ______________________________

School: ______________________________

Date: ______________________________

Hofstra University Center for
Technological Literacy
**Simulations and Modeling for
Technology Education**

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In this KSB, you will learn how to design a structure so that it stands up under its own weight and under external loads. The structure that you design will be a water tower. The ideas you learn in designing the water tower will provide you with background you need to design your survival shelter so that it too, stands up under load. **KSB 4 should take you five periods of class time.**

THERE ARE FIVE PARTS TO KSB 4 (PARTS A - E). EACH PART HAS SOME KEY IDEAS TO LEARN. EACH OF THESE KEY IDEAS WILL BE EXPLAINED CLEARLY; FOR NOW, JUST READ THEM OVER BRIEFLY.

KSB 4A: Dead loads, live loads, and wind loads are among those that have to be taken into consideration when designing a structure **(one period of class time)**.

KSB 4B: Structural integrity refers to the ability of individual structural members that comprise the structure (and their connections) to perform their functions under loads **(one period of class time)**.

KSB 4C: Selecting materials involves making trade-offs between qualities **(one-half period of class time)**.

KSB 4D: The overall stability of a structure and its foundation refers to its ability to resist overturning (toppling over) and lateral movement (sliding) under load **(two periods of class time)**.

KSB 4E: Structural design is influenced by function, appearance, cost, and climate/ location **(one half period of class time)**.

You will need the following materials and equipment to do these KSBs:

- Access to the Internet
- About 30 drinking straws, ¼” diameter, about 10-12” long
- A block of modeling clay about 8” long x 8” wide x 4” high.
- Hot glue gun and glue sticks
- Safety goggles
- A square of corrugated cardboard, about 6” on a side
- An electric fan

SAFETY NOTES:

You are going to be working with a hot glue gun and hot glue. **Hot glue when used doesn’t look hot, but it is**. Be really careful. **Don’t touch the hot glue or the glue gun once it gets hot**. Be sure to wear safety goggles whenever you are working with hot materials.

INTRODUCTION:

Early in human history, people had no permanent structures to live in. They lived a nomadic life and moved from place to place. They lived in caves or under a bush. They didn't have the technology to build structures that would shelter them from the weather or from dangerous animals.

As people began to roam away from their own territory to hunt for food, they developed the need to build shelters. The first type of building construction was probably a simple shelter to protect people from rain and wind. Teepees made from animal hides stretched over a wooden frame were in use as long ago as 20,000 BCE. These homes were moveable and people could take them along as they searched for new sources of food.

Figure 1**:** Simple Structures built by Bedouins

As people began to settle in villages, they needed more permanent houses. Natural materials like wood, stone, and mud were used. Later, bricks made from straw and mud were used to construct houses. At present, we find many kinds of structures in the built environment. Some are still quite simple like those built by the Bedouins (*desert-dwelling Arabic people, see Figure 1*) who still live semi nomadic lives.

As technology evolved, great pyramids built from blocks of limestone were built by the Egyptians as early as 3000 BCE. The Romans were great engineers. They built cities and roads, and erected bridges in the first century CE. Structures include bridges, buildings, dams, harbors, roads, towers, and tunnels. Each of these structures requires special construction techniques that have been learned through centuries of experience. Today, we combine that past experience with engineering data and knowledge about the properties of materials and about how they will act under conditions of stress.

The Roman Colosseum complete in 80 CE

Since you are building a survival shelter, you will have to use proper techniques and knowledge to make sure that the shelter keeps your team members safe and reasonably comfortable until the rescue team can reach you.

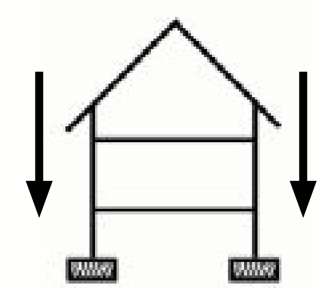
Take a look at some very simple shelter designs at http://solareagle.com/PREP/SHELTER.HTM

KSB 4A : DEAD LOADS AND LIVE LOADS ARE AMONG THOSE THAT HAVE TO BE TAKEN INTO CONSIDERATION WHEN DESIGNING A STRUCTURE.

Dead load is the weight of the structure itself and permanent fixtures. Dead loads are loads which are always fixed in position, and of unchanging magnitude. Dead loads always act vertically.

Examples would be:

- the weight of materials from which the structure is built
- the weight of permanent equipment, such as water or gas pipes, electric cables, etc.

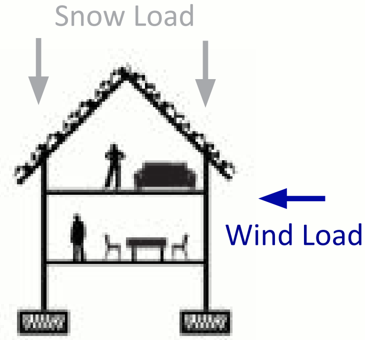


DEAD LOAD

Live loads are loads that are temporary or moving and can vary in magnitude.

Examples would be:

- goods stored on a floor
- furniture, file cabinets, or moveable objects in an office
- people in a building
- cars or trains on a bridge



LIVE LOADS

Notice that some live loads **move** (cars, trucks, trains, etc.) and some are moveable (goods, furniture, file cabinets, etc.).

Wind and snow loads are a special case of live loads, but since they can create other effects (for example, wind can create a vacuum effect on a roof), engineers consider them separately. When you design your shelter, you must design it so that it stands up under dead load and any live load.

CHECK YOUR UNDERSTANDING

Define dead load and give some examples. **Explain below** why dead load needs to be considered in structural design.

Define dead load and give some examples. **Explain below** why dead load needs to be considered in structural design.

POINTS TO PONDER

DISASTERS CAUSED BY STRUCTURAL DESIGN ERRORS

DEAD LOAD DISASTER

An example of a disaster that occurred because the structural design engineer made a serious error in calculating dead load was the Hotel New World disaster that occurred in March 1986. Click on the links below and read about this disaster:

http://en.wikipedia.org/wiki/Hotel_New_World_disaster
http://www.911myths.com/html/progressive_collapse.html
http://covertoperations.blogspot.com/2009_05_01_archive.html

Photo courtesy of: http://covertoperations.blogspot.com/2009/05/actual-gravitational-collapse-singapore.html

LIVE LOAD DISASTER

On July 17, 1981, approximately 2,000 people had gathered on hotel walkways at the Hyatt Regency hotel in Kansas City to watch a dance contest down below. Because the design of the walkway was flawed, it collapsed under the additional live load. The walkways came crashing down and 114 people were killed. Read about this disaster at:
http://en.wikipedia.org/wiki/Hyatt_Regency_walkway_collapse

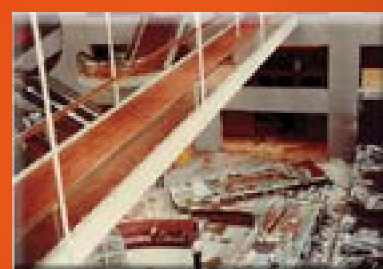


Photo courtesy of: Dr. Lee Lowery, Jr., P.E. Photo in public domain http://ethics.tamu.edu/ethics/hyatt/hyatt2.htm

WIND LOAD DISASTER

The Tacoma Narrows Bridge collapsed in November 1940 due to wind loads that caused enormous vibrations in the bridge. Read about this bridge collapse at:
http://en.wikipedia.org/wiki/Tacoma_Narrows_Bridge_(1940)
and see the amazing video of the collapse at:
http://www.youtube.com/watch?v=HxTZ446tbzE

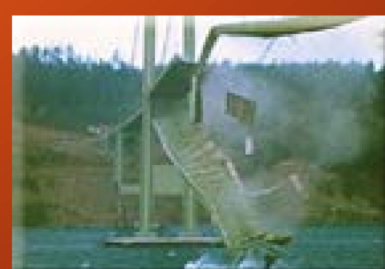


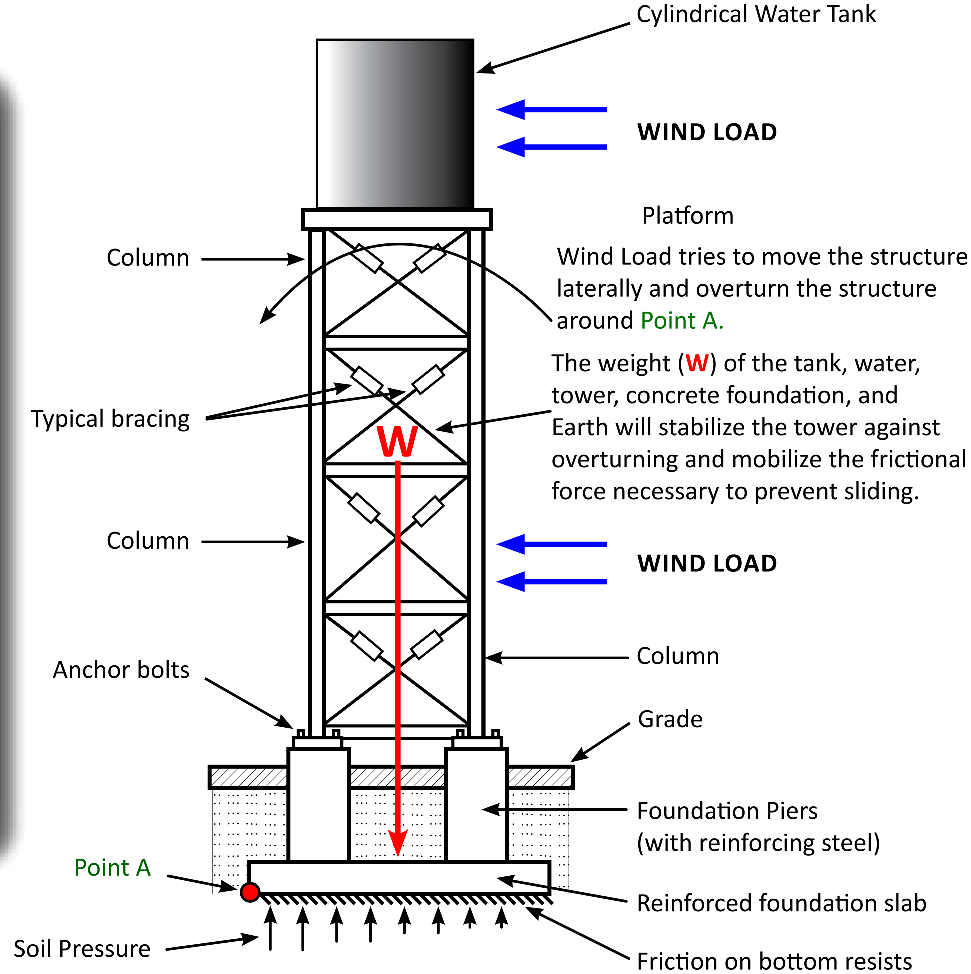
Photo courtesy of: www.cflhd.gov/agm/images/fig64.jpg

IN THE NEXT SECTION, YOU WILL BE ASKED TO IDENTIFY THE LIVE AND DEAD LOADS THAT ACT ON A WATER TOWER.

POINTS TO PONDER

Look carefully at the drawing of the water tower, to the right.

The tower is supporting a water tank. Identify the live loads and the dead loads shown in the drawing.



BRACED TOWER

CHECK YOUR UNDERSTANDING

Specify whether each of the following is a dead load or a live load by **putting a check in the appropriate box**.

LOAD	DEAD LOAD	LIVE LOAD
Water tank itself	☐	☐
The tower itself	☐	☐
Wind	☐	☐
Water sloshing around in the tank	☐	☐

KSB4B: STRUCTURAL INTEGRITY REFERS TO THE ABILITY OF INDIVIDUAL STRUCTURAL MEMBERS THAT COMPRISE THE STRUCTURE (AND THEIR CONNECTIONS) TO PERFORM THEIR FUNCTIONS UNDER LOADS.

THINK LIKE AN ENGINEER

MAKE SOME PREDICTIONS: Water weighs about 8.33 pounds per gallon. If the water tank on top of the tower shown below holds 500 gallons of water, the weight of the water in the tank = 8.33 x 500 or about 4165 pounds. When the tank is filled, this tower has to support a substantial dead load.

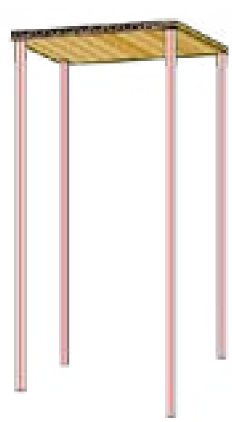
What do you think would happen to the vertical columns if the water tank was filled with 500 gallons of water and the tower columns were very thin? **(Write your prediction below)**

What effect do you think that bracing the columns horizontally would have?
(Write your prediction below)

NOW YOU'LL HAVE A CHANCE TO TEST YOUR PREDICTIONS!

KSB 4C : SELECTING MATERIALS INVOLVES MAKING TRADE-OFFS BETWEEN QUALITIES.

1. BUILD A MODEL AND TEST YOUR PREDICTIONS.



One easy way to do this is to build a model using four 1/4” diameter drinking straws that are about 10”-12” long and a platform made from a 6” x 6” square of corrugated cardboard. Attach the straws to the platform close to the corners with glue. You can use a cool melt glue gun, or a hot glue gun (but the drinking straws will melt if the glue temperature is too high). Build the model upside down. Squeeze a bit of glue on to the cardboard and allow it to cool for about three seconds. Then hold the end of the straw so that it sits in the glue while it cools. Be careful that you don’t touch the hot glue. Now, put books on top of the tower, one at a time. What happens to the “columns?” **(Write your answer below)**

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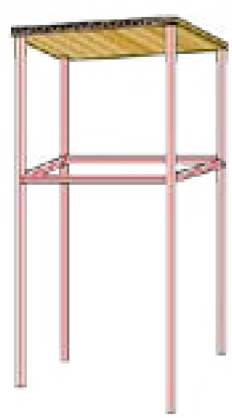
2. NOW MAKE ANOTHER MODEL, BUT THIS TIME, ADD HORIZONTAL BRACING AS SHOWN.



You can make the bracing from another set of drinking straws, or you can use strips of balsa wood. Glue them to the center of the columns. Again, place books on the tower platform. Does the braced tower support more weight than the unbraced tower? Write down your observations. What effect did the horizontal bracing have? **(Write your answer below)**

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What conclusions have you reached about what will provide your tower with structural integrity? (That is, what will improve the ability of individual structural members that comprise the structure (and their connections) to perform their functions under loads? **(Write your answer below)**

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KSB 4D : THE OVERALL STABILITY OF A STRUCTURE AND ITS FOUNDATION REFERS TO ITS ABILITY TO RESIST OVERTURNING AND LATERAL (SIDEWAYS) MOVEMENT UNDER LOAD.

What do you think would happen to strength of the tower if you used metal for the columns instead of drinking straws?

Take the model you've made (*Figure 2*) and insert a 3/16" diameter, 10" long steel rod into each of the straw columns (*Figure 3*).

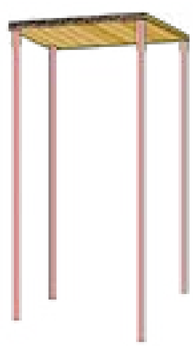

Figure 2: Tower

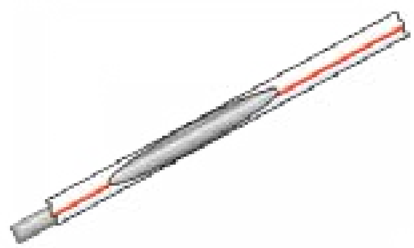

Figure 3: Straw (cutaway) with rod inside

What do you notice about the ability of the tower to support more weight? **(Write your description below)**

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POINTS TO PONDER

A trade off is giving up one thing to get something else, normally an improvement. In making this improvement to the column, what trade-offs did you make? (What did you gain, what did you lose?) **(Write your answer below)**

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If you had used a metal platform instead of corrugated cardboard, what trade-offs would you have made? (What did you gain, what did you lose?) **(Write your answer below)**

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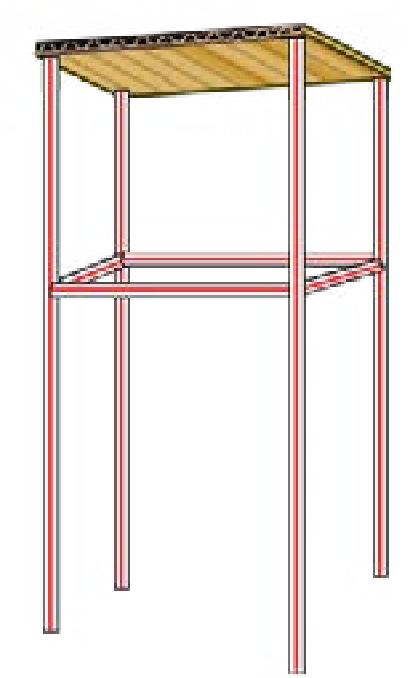
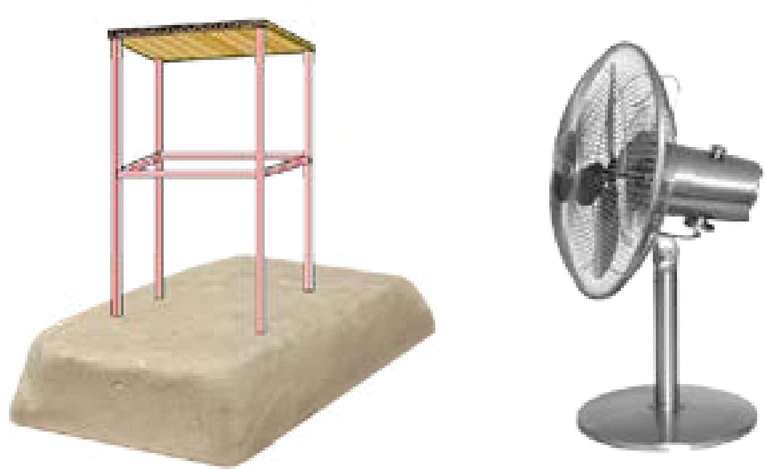
1. **OBTAIN A FAN FROM YOUR TEACHER AND ADD WIND LOAD TO YOUR TOWER.**



Describe what happens to your tower when the wind blows. **Write your description below.**

2. **NOW MAKE A FOUNDATION FOR YOUR TOWER. AN EASY WAY TO DO THIS IS TO USE A LARGE BLOCK OF MODELING CLAY AND STICK THE STRAWS 3" INTO THE CLAY. TURN THE FAN ON AND WATCH WHAT HAPPENS.**



Under wind load, does the tower stand up or does it try to overturn? Explain what you see. **Write your description below.**

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This tower known as the Leaning Tower of Pisa (Figure 4) in Italy was built in 1173. The reason that the tower leans is that soil the foundation was not strong enough to hold the weight of the tower and the condition became worse under wind loading.

The tower is built on layers of sand and clay. Engineers calculate that the pressure was 20 pounds/square foot - unheard of for soil. When the wind blows, the pressure increases even more.

http://funphysics.jpl.nasa.gov/story/leu-demo.html

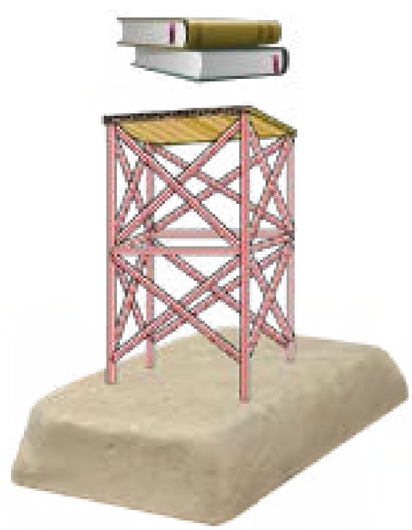
Figure 4: Leaning Tower of Pisa

3. **NOW ADD CROSS BRACING TO YOUR TOWER.**

   Again, you can make the cross bracing from drinking straws or balsa wood strips or any other material your teacher suggests.

Turn on the fan again, and describe the effect of adding cross bracing to your tower. Does the tower stand up or does it try to overturn? Explain exactly what you see. **Write your explanation below.**

4. **FINALLY, PLACE A LOAD ON TOP OF THE TOWER PLATFORM (USE A BOOK OR A COUPLE OF BOOKS) AND AGAIN TURN ON THE FAN.**



Does the tower become more or less stable with a weight on the top? **Write your answer below.**

Why do you think this is so? **Write your answer below.**

CHECK YOUR UNDERSTANDING

Do you think a water tower is more or less stable when the water tank is filled or empty? **Explain your answer below.**

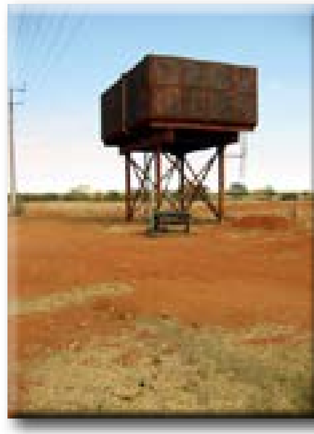
What do you think the **stability** of a structure refers to?
Select the correct answer below by placing a checkmark.

- ☐ **A.** Its ability to resist overturning and lateral (sideways) movement under load.
- ☐ **B.** Its ability to survive under any and all conditions
- ☐ **C.** Its ability to stand up under load, even without a foundation.
- ☐ **D.** Its ability to stand up even without any bracing.

Look at these towers. Notice the geometric shapes of the water tanks.

#1 Water tower in Ohio

#2 Water tower in Michigan



#3 Raised Australian water tower

#4 Colonial style water tower in Florida

THINK LIKE AN ENGINEER

From what you learned in KSB 1 about surface area and volume of various geometric shapes, which of the above water tank shapes (1, 2, 3, or 4) would create the least wind load assuming they all contained the same volume of water?

Write your answer below

______

The most?
(Write your response to the right)

______

Why? **(Write your response below)**

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KSB 4E : STRUCTURAL DESIGN IS INFLUENCED BY CLIMATE AND LOCATION, FUNCTION, APPEARANCE, AND COST.

Structures are built for a wide variety of purposes. Bridges, buildings, dams, harbors, roads, towers, and tunnels are all projects that are constructed. Structures are built to be appropriate for their climate and location, their function, cost limitations, and appearance.

Climate and location influence structural design. Structures that are built in deserts need different kinds of anchoring systems and foundations than structures built on rocky ground. You might be interested in the article about temporary desert structures at http://wps.com/BM/bluetarp_files/bluetarp.htm

In areas where earthquakes are likely, buildings are strengthened using special construction techniques. These include framing made from steel, using cross bracing techniques, and using rubber pads to cushion the structure when it shakes. When there are very large earthquakes that cause a high death toll, it's usually buildings that collapse that cause the most deaths. The 49-story Transamerica Pyramid office building (*Figure 5*) in San Francisco, built to withstand earthquakes, swayed more than 1 foot but was not damaged in a major California earthquake in 1989.

***Figure 5*: Transamerica Pyramid**

Buildings on higher mountainous elevations are regulated by building codes because tall buildings on mountains can be a danger to air navigation, are subject to high winds, and could detract from the natural beauty of the mountains. In rural mountainous areas, transport of materials is much more complicated than in more accessible areas, so in those hard-to-reach areas, construction relies on locally available materials.

Because the cost of land in cities is so expensive, skyscrapers are built as apartment and office buildings. Not surprisingly, all of the world's tallest buildings are in cities. To see them, visit http://aibek.nomadlife.org/uploaded_images/tall_buildings-784313.jpg The tallest building in the world in 2010 is in Dubai in the United Arab Emirates. It is over 800 meters (2625 feet) high.

A Japanese construction company is considering building even a taller building. Their idea is to construct a building that would be 13,123 feet high and overshadow Mount Fuji. It would be taller than nine Empire State Buildings and is envisioned to be able to house 1,000,000 people on 800 floors. To read about it, go to http://inventorspot.com/articles/worlds_tallest_building_be_talle_6398

Permafrost is frozen soil. People in places like Barrow, Alaska about 350 miles north of the Arctic Circle must build their homes on stilts to prevent the heat from within the home melting the permafrost soil which would cause their homes to sink into the earth. For a set of additional images of houses on stilts, visit the following website:

http://images.google.com/images?q=houses+on+stilts&hl=en&rls=com.microsoft:en-US&um=1&ie=UTF-8&ei=LOeeS9yMIIG78gaNqcXtCw&sa=X&oi=image_result_group&ct=title&resnum=1&ved=0CBQQsAQwAA

Figure 6**:** Barrow, Alaska

Function. Form follows function is a principle associated with **modern architecture** and **industrial design** in the 20th century. The principle means that the shape of an object will naturally be based upon its intended function or purpose. A great example is if the function of a building is to hold many, many people at a low square foot construction cost, the form that evolves is a skyscraper. Another example is how the form of a suspension bridge has evolved based on its function of spanning a very wide area.

CHECK YOUR UNDERSTANDING

1. **In the space below**, explain how climate and location influence structural design.

CHECK YOUR UNDERSTANDING

2. Find two examples on the Web or other sources of structures of any type that were built for specific climates or locations. **Copy and paste pictures of these structures below in the spaces provided.** Then describe the environment **(in the spaces provided on the right)** for which they were built.

Environment for which structure 1 was built

Structure 1

Environment for which structure 2 was built

Structure 2

Cost is a very important consideration when designing and building structures. When architectural and engineering firms are asked to design a structure for a client, they are invited to submit bids. A **bid** is an offer to design the structure for a specific amount of money within a specified time period with a guarantee that the structure meets all the building codes and engineering specifications.

Companies submit competitive bids to the client who then chooses the company that will build the desired structure to specifications, at the lowest cost. Normally, when a structure is designed, **trade-offs** are made. Remember that a trade-off is giving up one thing to get something else. Sometimes, cost-benefit trade-offs are made. For example, changes are made in using less expensive materials. The architect may decide to change the appearance and trade off appearance for cost. Or, an emergency shelter could be made so that it would withstand a heavy snow load but that might require more construction time. Designers and engineers have to consider these trade-offs constantly and make the best decision that strikes a balance between all the variables. Making decisions that balance all the variables is called *optimization.*

Appearance is another factor that often drives design decisions. Well-designed structures are often extremely beautiful to look at. Homes, office buildings, airport terminals, and other constructed environments will be more appealing to prospective tenants and purchasers if their exteriors and interiors are attractive to look at.

The appearance of a structure is often a function of its color, shape, proportions, its "character" (that is, whether it looks modern or medieval (*Figure 7*), simple or magnificent, sleek or sprawling), and how well it blends into its environment (*Figure 8*).

Figure 7: Sir Ronald Storrs (first British military governor of Jerusalem) enacted a bylaw in 1918 requiring that all new buildings use (or are faced with) Jerusalem Stone, to preserve the city's architectural style.

http://en.wikipedia.org/wiki/Jerusalem_stone

Figure 8: This bamboo structure has an aesthetic appeal and blends into the natural environment.

http://www.bamboo-inspiration.com/bamboo-construction.html

THINK LIKE AN ENGINEER

Since you are designing and building an emergency shelter, some design considerations are going to be much more important than others. **In the table below**, list the most important factors and also list those that are not important and might even be disregarded. In doing so, think about the main purpose of your shelter and the design specifications that you were given.

Critical Design Features for your Shelter	Explain Why this Feature is Critical

Shelter Design Features that are *not* Critical	Explain Why this Feature is not Critical

SUMMARY QUESTIONS

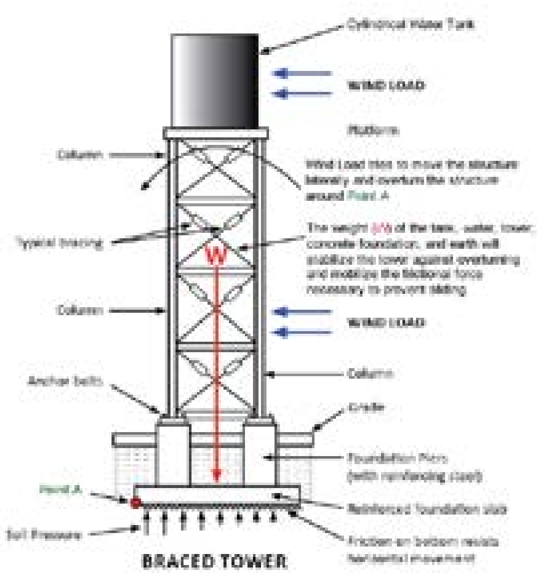
What types of loads have to be taken into consideration when designing a structure?

2. Why are water tanks made in a spherical or cylindrical shape rather than a different geometric shape such as a rectangular prism, a square-based pyramid?

3. What function does a foundation serve?

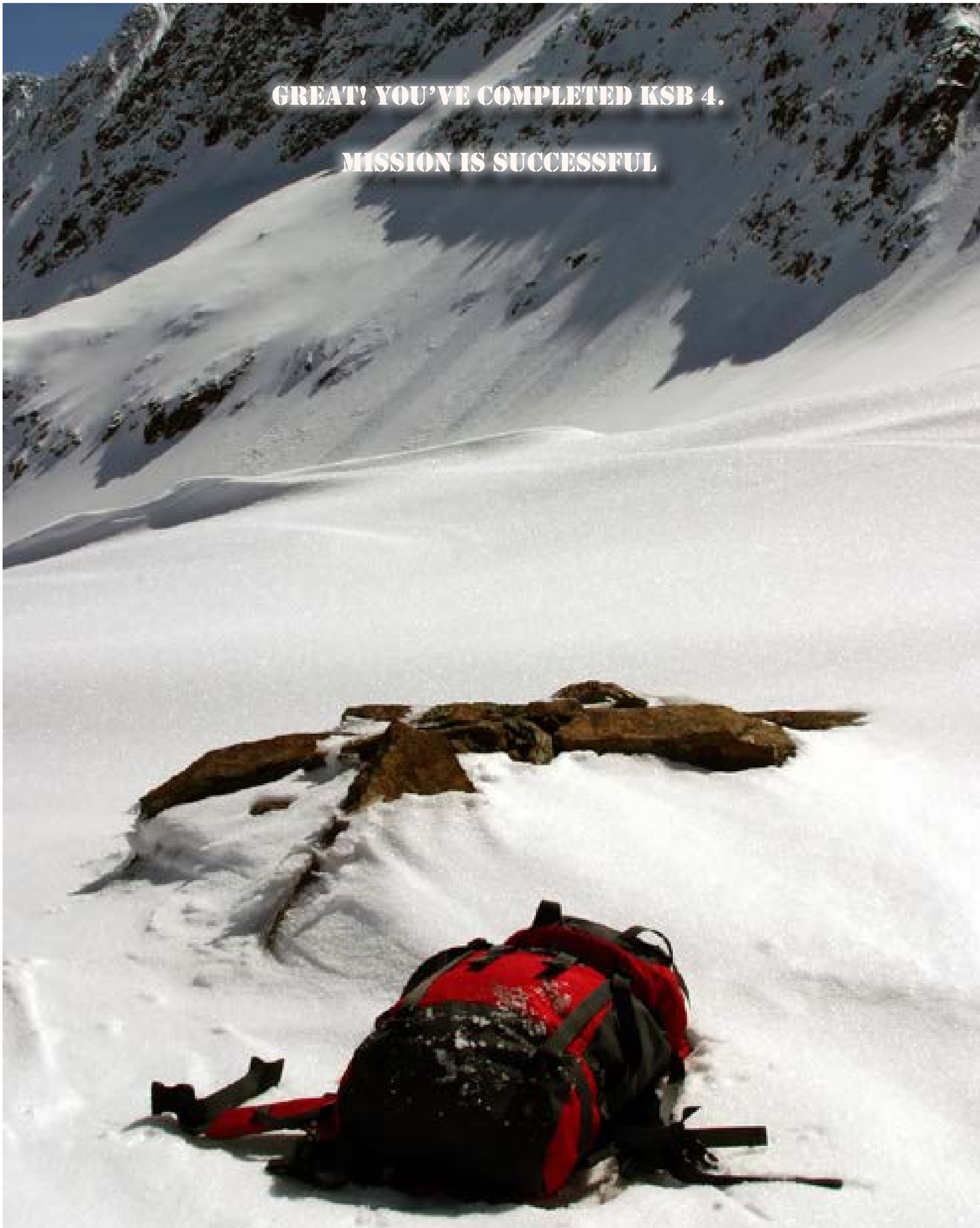
4. What design element principally provides a structure with the stability to resist overturning when it is subjected to wind load?

5. In the diagram to the right, what loads did the engineer have to consider when designing the tower?



6. Give an example of a trade-off that a structural engineer might have to make when selecting materials to be used in constructing a water tower.

7. Explain how structural design is influenced by cost and climate/location.


GREAT! YOU'VE COMPLETED KSB 4.
MISSION IS SUCCESSFUL