STRUCTURES AND FORCES

GRADE 7 SCIENCE

STUDY GUIDE

Structures and Forces Curriculum Overview

A. Describe and interpret different types of structures encountered in everyday objects, buildings, plants and animals, and identify materials from which they are made.
   1. Recognize and classify structural forms.
   2. Interpret examples of variation in the design of structures that share a common function, and evaluate the effectiveness of the designs.
   3. Describe and compare example structures developed by different cultures and at different times, and interpret differences in functions, materials and aesthetics.
   4. Describe and interpret natural structures, including the structure of living things and structures created by animals.

B. Investigate and analyze forces within structures, and forces applied to them.
   1. Recognize and use units of force and mass, and identify and measure forces and loads, including tension, compression, shear, torsion and bending.
   2. Identify examples of frictional forces and their use in structures.
   3. Identify causes of structural failure and infer causes of failure from actual examples.

C. Investigate and analyze the properties of materials used in structures.
   1. Devise and use methods of testing the strength and flexibility of materials used in a structure.
   2. Identify points in a structure where flexible or fixed joints are required, and evaluate the appropriateness of different types of joints for the particular application.
   3. Compare structural properties of different materials, including natural materials and synthetics.
   4. Investigate and describe the role of different materials found in plant and animal structures.

D. Demonstrate and describe processes used in developing, evaluating and improving structures that will meet human needs with a margin of safety.
   1. Demonstrate and describe methods to increase the strength of materials through changes in design.
   2. Identify environmental factors that may affect the stability and safety of a structure, and describe how these factors are taken into account.
   3. Analyze and evaluate a technological design or process on the basis of identified criteria, such as costs, benefits, safety and potential impact on the environment.

A. Describe and interpret different types of structures encountered in everyday objects, buildings, plants and animals, and identify materials from which they are made.

1. Recognize and classify structural forms. (Pg. 264-268 in text)

They are all around us. They are everywhere we look and everywhere we go. They come in all shapes and sizes. Some are made by people, some are natural. Some are super ugly, others are simply beautiful. Do you need a few more clues to guess what they are? We live in them, go to school in them, and drive in them. They protect our heads from nasty bike crashes, keep our feet dry on wet days, and make up the framework of our body. They are mountains, spider webs, ant hills, beaver dams, and trees. They include the unimaginably huge universe with its millions upon millions of galaxies and stars. They also include atoms which are too small to be seen with the naked eye. They're all structures. Think of structures as a combination of parts that belong together. Matter is arranged into objects known as structures. Structure refers to how the parts of an object relate to each other and how it is put together.

Structures can be classified into three distinct types: solid, frame or shell. Some structures are combinations of these three.

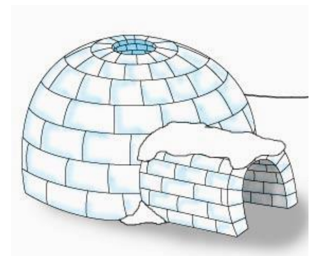
- Examples of solid structures - Early examples of solid structures would include caves and stone huts. As the title suggests solid structures rely heavily on solid construction such as cement to support loads and to transfer these loads safely to the ground. Solid construction was more widely used in the past due to the fact that they were the only materials available.



- Examples of frame structures – these are made of several individual parts fastened together to make a supportive structure.




- Examples of <u>shell structures</u> - In shell (or surface) structures the load-bearing elements or surfaces performs two functions: It defines the space to be enclosed; It provides support. Surface structures have only started to gain popularity due to the wide variety and availability of materials.



- Examples of frame-and-shell structures – As the name implies, these are a combination of two different kinds of structures and are very common in modern architecture.

2. Interpret examples of variation in the design of structures that share a common function, and evaluate the effectiveness of the designs.
(Pg. 269-275 in text)

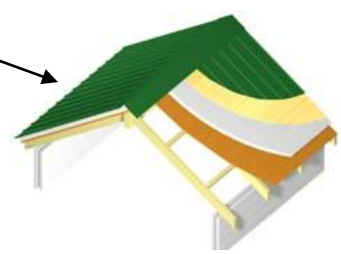
Structures are designed by both man and nature in order to fulfill some specific <u>function</u> which refers to their use and purpose. In the natural world, this relates to natural selection or "survival of the fittest". In our society, this relates to some human needs or wants.

Common functions include support and protection.

SUPPORT



PROTECTION


3. **Describe and compare example structures developed by different cultures and at different times, and interpret differences in functions, materials and aesthetics.** (Pg. 276-278 in text)

Structures have developed gradually over time but there were two main factors that affected the development of structures:

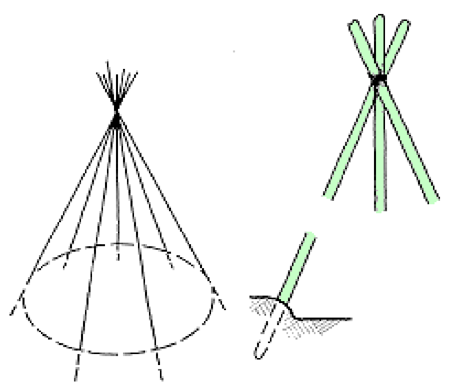
- The availability of tools for cutting and shaping.

  During the Stone Age, stone axes and flints were used to cut the wood but, due to the nature of the tools, methods of jointing were limited. With the advent of the Bronze and the Iron Age, new materials were available and therefore improved tools.

- Methods of construction and building techniques.

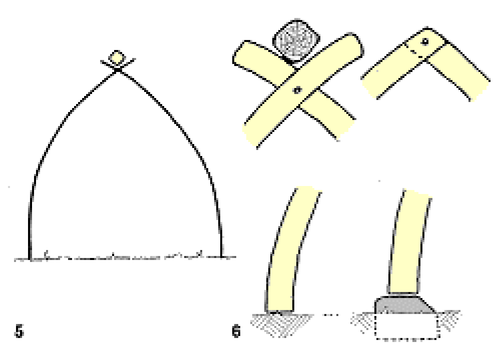
  As people's needs changed, so did their building techniques. With the improvement in the different types of tools that were available, there was also a development in the methods of construction, such as improved jointing techniques.

As these two factors changed over time, so did the type of structures that were being constructed. We will take the example of timber and trace its development in the use of construction.

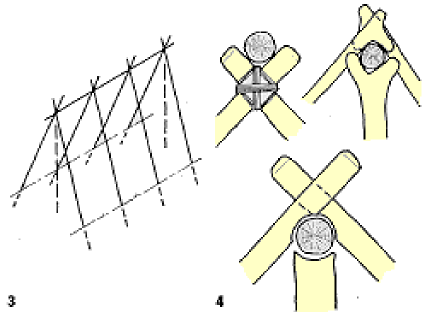


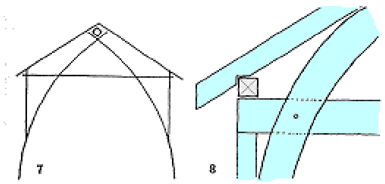
Early structures such as this circular hut were constructed from branches and stakes and they were jointed at the apex using strips of bark. No tools were required in the construction of such a hut.

With the development of tools such as stone flints, basic jointing started to occur. It evolved from being tied as above to the use of natural forks and finally basic shaping and jointing.



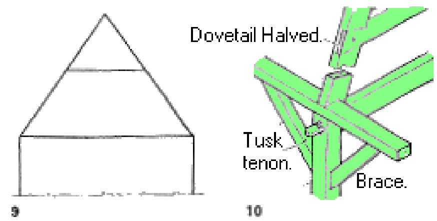
Frames started to change shape and developments started to occur not only in the jointing but also in the foundations. The introduction of dwarf walls meant that the structure was no longer depending solely on the ground for support.





Structural members started to become more square in section and more elaborate jointing was used.

As structures developed, separate framing was used for the walls and the roof. From the detail of the jointing system it can be seen that more elaborate joints were used. This was a result of the fact that tools also improved.



Examples of structures from different cultures that serve the same function. Notice the aesthetics (the quality of beauty) from different cultures.

Brick

Sod

Clay (adobe)

Pagoda

Chalet

Amazon Hut

4. Describe and interpret natural structures, including the structure of living things and structures created by animals. (Pg. 319 – 321 in text)

"There is nothing new under the Sun." This does not mean that everything has been built already but that the principle behind the design already exists. By examining structures in nature we can see where the principle exists and see how these principles are incorporated in structures today. One thing we have to keep in mind when comparing natural and manmade structures is that nature uses live materials while man uses inert ones and the two do not always behave in the same manner. An example of this is if you buy a pair of shoes the soles will wear over time, whereas the soles of bare feet actually grow thicker with excessive use.

We also have to remember that nature has had a much longer time to perfect its designs and just like man learns from his mistakes so to does nature. Living things have evolved structures that are so complex and so efficient that often man's best efforts look clumsy in comparison.

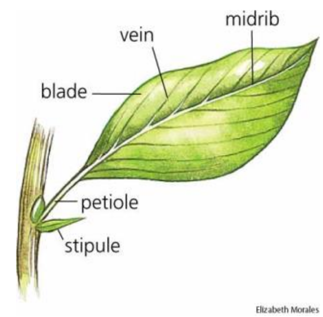
There are three main types of functions in natural structures:

- Support structures
  - Skeletons in animals – external (insects) or internal
  - Trunks and stems in plants
  - A variety of feet – hooves, claws, pads

- Materials and structures to gain food
  - Broad leaves on plants to collect sunlight
  - Different types of teeth (canine, grinding)
  - Feeding tubes (humming birds, mosquitoes….)

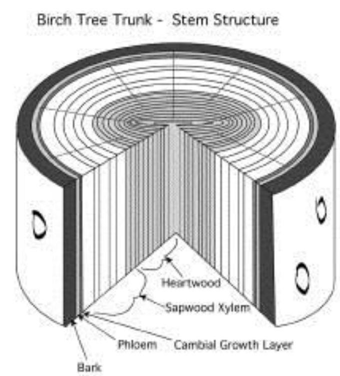
- Materials and structures to gain motion
  - Fins and flippers in water, smooth skin means less resistance in water
  - Feathers and wings
  - Flexible joints, muscles

Natural structures can be divided into three categories: structures in plants; structures in animals and; structures that animals build.



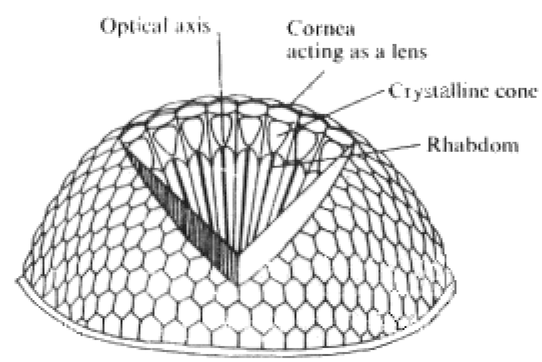
Structure in Plants

` closely at a leaf you can see how the main rib tapers from the base, the point where the whole weight of the leaf is borne from. The other ribs spring from the centre rib in a regular pattern and taper from the centre to the edge. The whole leaf can be looked at as the way nature has evolved a mechanically sound structure that elegantly performs its desired functions in the conditions in which it grows. A leaf is a perfect example of a lightweight structure in nature.

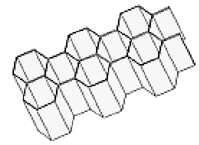


Structure of Animals

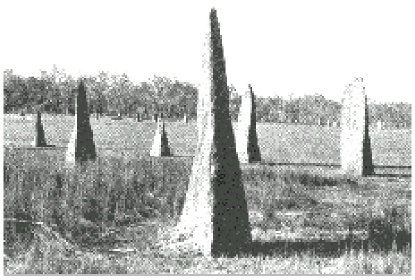
The image opposite illustrates the structure of an insect's eye, which is composed of many parts and all these parts have to be held together and supported. This is done by a geodesic dome grid on the outside surface of the eye which by its nature takes the shape of a hemisphere. The whole structural framework of the domed grid is held firmly in position and this in turn provides a stiff and strong support for the cornea. This enables the insect's eye to function efficiently. The concept behind the geodesic domes which Buckminster Fuller designed are the very same as the structure of an insect's eye. The insect's eye is not the only place where geodesic forms are found in nature. They also occur in many cell structures, such as spherical groups of carbon atoms called buckyballs as well as viruses, enzymes and even small organisms.



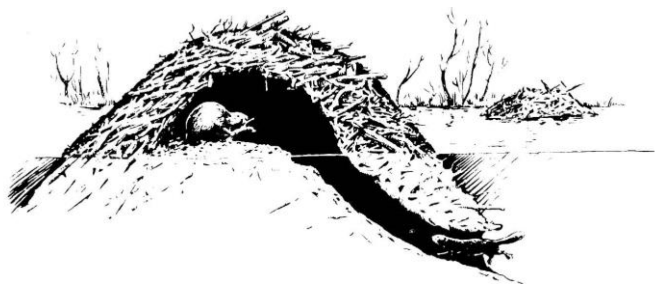
Structures that Animals Build



Insects and animals play a more active role in the building of their homes. The web of the spider, the dam or lodge of a beaver or the structure of the termite are designed in such a manner as to support the creature's activities. The diagram opposite is a section of the honeycomb cell structure from a beehive. The honeycomb is constructed in such a way that it can contain the maximum amount of honey for the minimum amount of wall surface. This in turn requires the minimum amount of energy by the bees when constructing the beehive.

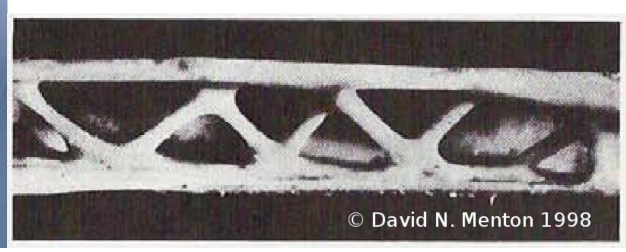


Termite Mounds



Beaver Lodge

Snail Spiral Shell



Bird Hollow Bones

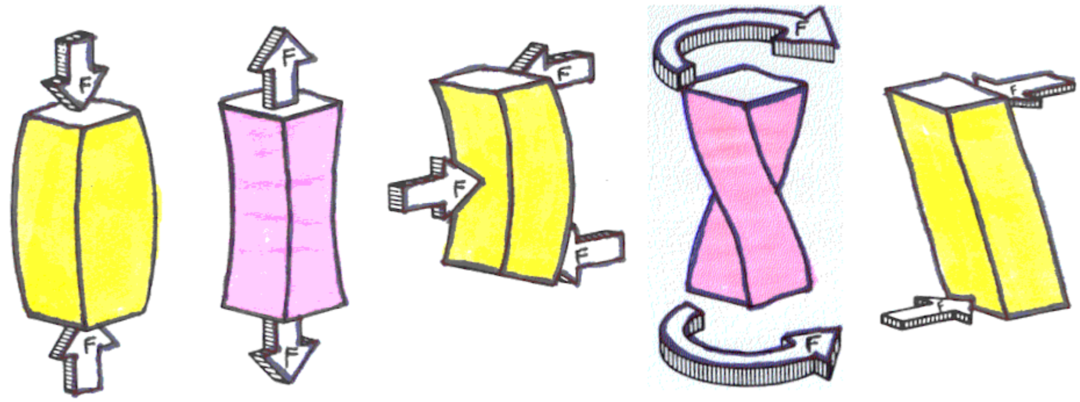
B. Investigate and analyze forces within structures, and forces applied to them.

1. Recognize and use units of force and mass, and identify and measure forces and loads. (Pg. 281 - 284, 296 – 299 in text)

A force is a push or a pull, or more generally anything that can change an object's speed or direction of motion. A force is required to start a car moving, to slow down a baseball player sliding in to home base, or to make an airplane turn. Forces may fail to change an object's motion if they are canceled by other forces, e.g. the force of gravity pulling you down right now is being canceled by the force of the chair pushing up on you. When nothing is moving, forces are balanced. The metric unit of force is the Newton (N).

Forces may be internal (forces acting within the structure itself) or external (forces acting on the object from the outside).

Type of Force (Internal)	Description of Force
Compressional Force	Compression is the force which is transferred through an object when it is pushed on by a load.
Tensional Force	Tension is the force which is transmitted through a string, rope, or object being bent when it is pulled tight by forces acting from each end.
Shear Force	Shear is a force tending to cause deformation of a material by slippage along a plane or planes parallel to the imposed stress. _This force acts similarly to a pair of scissors cutting through paper.
Torsion or Torque Force	Torsion or torque is a force that tends to rotate or twist things. You generate a torque any time you apply a force using a wrench. Wringing out sponge applies torque to the object.
Type of Force (External)	**Description of Force**
Gravity Force (also known as weight)	The force of gravity is the force at which the Earth, Moon, or other massively large object attracts another object towards itself. By definition, this is the weight of the object. All objects upon earth experience a force of gravity which is directed "downward" towards the center of the earth. It pulls you down, or, more exactly, toward the center of the Earth. It is proportional to mass so the more mass, the more the gravitational force.
Friction Force	The friction force is the force exerted by a surface as an object moves across it or makes an effort to move across it. The friction force opposes the motion of the object. For example, if a book moves across the surface of a desk, then the desk exerts a friction force in the opposite direction of its motion.
Wind	Wind is a lateral (sideways) force that especially affects tall buildings and bridges.



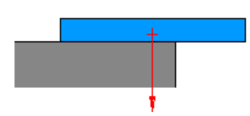
Compression *Tension (stretched)* *Bending* *Torsion (torque)* *Shearing*

Factors that affect how forces will act on a structure:

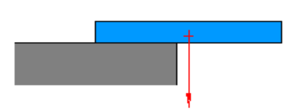
Load – These are stresses to structures from external or internal forces.

- Static or dead loads are gravity loads that are constant throughout the structure's life. These include equipment such as fans, suspended heaters and plants suspended from the frame.
- Dynamic or live loads are temporary, such as people and cars on a bridge, snow loads and wind loads. They can also be combination loads such as during a snowstorm with high winds.

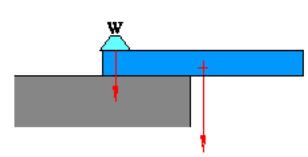
Centre of gravity - gravity acts downwards so the weight of any structure or any part of a structure acts vertically downwards. We assume that the whole weight of a structure acts through one point - the centre of gravity. The centre of gravity of a body is the point at which its entire weight can be considered to act. In most common circumstances the centre of gravity and centre of mass can be considered to be in the same place. They will be different if the gravity field is different at different points in the object. The position of the centre of gravity will depend on the shape of the body. To find it, you can balance an object at one point or it may be at the symmetrical centre of an object. The centre of gravity of an object does not necessarily have to be within a body, it can be an imaginary point in space. The centre of gravity is very important in relation to stability. If a line through the centre of gravity falls within the structures base then it will remain stable. If the line falls outside the structures base then there is a possibility that overturning will occur. This structure could be classified as unstable. In order to make such a structure stable precautions would have to be taken. One example is where part of the structure is secured to the base and this prevents overturning from occurring.



Stable

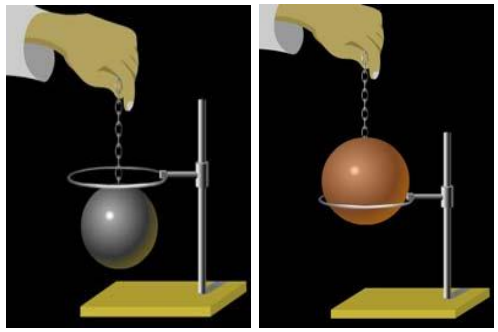


Unstable



Restored Stability

Thermal expansion and contraction – As you will recall from your heat and temperature unit, different materials have different expansion and contraction rates when subjected to heat and cold and these forces must be accounted for when designing a structure.



Cold ball passes through ring   Heated ball will not pass through ring after expansion.

2. Identify examples of frictional forces and their use in structures.
(Pg. 313 – 314 in text)

There is a force which acts to stop things moving. This is friction. Wherever two surfaces are in contact with each other a frictional force will be active. The size of the frictional force will depend largely upon the nature of the surfaces in contact; rough surfaces in contact tend to produce more friction than smooth surfaces. For example, it is harder to slide a piece of furniture across a carpet than across a polished floor.

Using Frictional Forces

- The force of friction resists movement between two surfaces that rub together. A brick wall is held together and kept evenly spaced with mortar, which helps to create large friction forces.
- Friction is also important in frame structures. The friction between the nail and the wood keeps the nail in place and the joints solid. Different types of nails provide differing amounts of friction.
- Friction between the ground and the bottom of a structure is an important design consideration. Friction holds the structure in place when external forces (wind) are acting on it. Too little, or too much friction can cause problems (moving chairs across the floor).

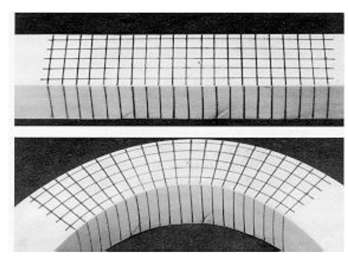
3. **Identify causes of structural failure and infer causes of failure from actual examples.** (Pg. 303 – 306 in text)

Deformation occurs when a structure changes shape because it is unable to support the load acting on it. All materials will deform but they are also elastic. That is, they change shape under load, like rubber, and spring back when the load is removed. Some are more elastic than others, of course. A steel spring is obviously elastic, and so is a car tire. However, stress can be greater than elastic strength. So when the stress is removed, it won't go back into shape, but stays as it is. If too much stress is put on a structure, it may fail to support its load. This can happen when a connection snaps, or it bends until it is useless, or a member in tension either pulls apart or a crack forms that divides it, or a member in compression crushes and crumbles, or, finally, if a member in compression buckles.

Fatigue and Failure

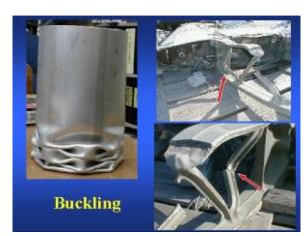
There are degrees to which a structure can be subjected to too much load.

- Structural fatigue occurs when there is repeated, excess stress on a structure. This may happen when a part is stressed, then released and then re-stressed such as a load on a chair. It may happen when there is a constant load and then additional periodic loads such as on a bridge, or it may be that there are opposite loads, some tension and some compression such as a spring on a rocking horse. It is common to begin to see small cracks in these materials.
- Structural failure occurs when a structure can no longer rebound from the load. In other words, the material will no longer rebound in an elastic way. There are several forms of structural failure:



Bending

- When opposite forces act on a structure (often a beam) causing it to deform.
- For example, when you walk across a simple beam bridge, the load pushes down in the middle but the ends of the bridge are supported by forces pushing up so it bends.



Buckling

- When the structure moves laterally and shortens under a load it can no longer support. Compression occurs at both ends, like crushing a can.
- Of all of the modes of failure, buckling is probably the most common and most catastrophic.

Fracturing

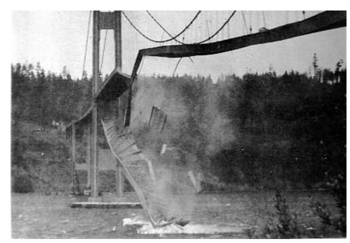
- Fracture of a structure or within a manufactured product will occur when fatigue cracks grow to a critical size. If the growth of fatigue cracks is not monitored and remaining life accurately predicted, catastrophic failure of the structure or manufactured product may occur without notice.

Structures and machines or their components fail because of fracture or excessive deformation. In attempting to prevent such failure, the designer estimates how much stress can be anticipated, and specifies materials that can withstand expected stresses. Structures are designed so that the material is never loaded beyond the limit at which the materials lose their elasticity. In this way we make sure that the members are resilient, always springing back into shape as soon as the load comes off, ready to change again when the next load is applied. However, structures do still fail, usually because of bad design, faulty construction, foundation failure, extraordinary loads, unexpected failure modes, or a combination of causes.

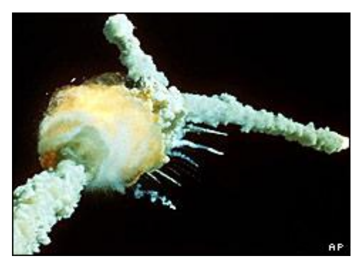
Code of Hammurabi 2200 B.C.:
If a builder builds a house for a man and does not make its construction firm and the house collapses and causes the death of the owner of the house - that builder shall be put to death. If it causes the death of a son of the owner - a son of that builder shall be put to death. If it causes the death of a slave of the owner - the builder shall give the owner a slave of equal value.

All structures must be built with a margin of safety which means that it must be built not only to withstand the predicted forces, but also to withstand possible unpredicted forces.

Tacoma Narrows Suspension Bridge Collapse
On November 7, 1940, at approximately 11:00 AM, the first Tacoma Narrows suspension bridge collapsed due to wind-induced vibrations. Situated on the Tacoma Narrows in Puget Sound, near the city of Tacoma, Washington, the bridge had only been open for traffic a few months.



Challenger Space Shuttle
On 28 January 1986, the American space program suffered one of its greatest tragedies when the Space Shuttle Challenger was destroyed 76 seconds into the mission, killing all seven crew members. The Shuttle was destroyed by a structural failure of an O-ring valve that caused the vehicle to break apart.



World Trade Centre

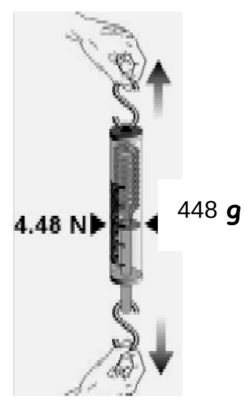
On Sept. 11, a terrorist attack brought down the World Trade Centre in New York. The plane hitting the building caused one storey to collapse and all floors above would have begun to fall. The huge mass of falling structure would gain momentum, crushing the structurally intact floors below, resulting in catastrophic failure of the entire structure. While the columns at say level 50 were designed to carry the static load of 50 floors above, once one floor collapsed and the floors above started to fall, the dynamic load of 50 stories above is very much greater, and the columns were almost instantly destroyed as each floor progressively "pancaked" to the ground. The heat from the burning fuel was also a factor in weakening the structural strength of the support columns.

C. Investigate and analyze the properties of materials used in structures.

1. Devise and use methods of testing the strength and flexibility of materials used in a structure. (Pg. 280 – 284 in text)

***How to use a <u>spring scale</u>*:**

Force is usually measured in grams (g) or Newtons (N). 1N = 100 g (about the weight of an apple). You are probably familiar with using grams (or kilograms) to measure weight but not force. However, when you measure weight, you are actually measuring force. <u>Weight</u> describes the force of gravity acting on an object. This is easy to see when you use a spring scale to measure weight. If you hang a 500 g weight on the end of a spring scale, the force of gravity between the object and Earth pulls the spring scale. The spring scale measures 500 g (or 5 N) of pull. If you remove the weight and pull down on the spring scale with your hand, your muscles, rather than gravity, provide the force.



Most spring scales have a small lever which allows adjusting the zero reading on the scale. It is very important that students "zero" their spring scales before making measurements. Note that the zero position must be adjusted when the spring scale is used upside-down. Otherwise, the weight of the scale itself will cause an error of approximately 0.2 Newtons.

Things to consider when measuring forces:

- Direction – is the force being applied upward, downward, or at an angle. If it is downward, remember that gravity is acting as an additional force.

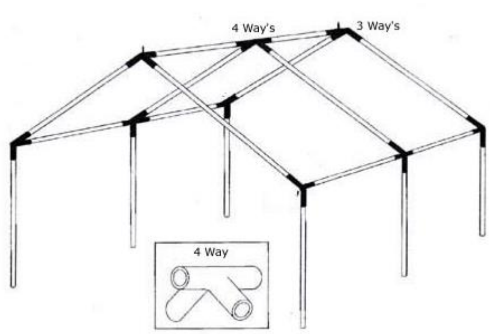
- Magnitude - how large is the force? This can be measured using a spring scale.

- Location – where is the force being applied? If it is in the middle of a bridge where there is no support, the force will have a far different effect on the structure than if is applied where there is a support beam.

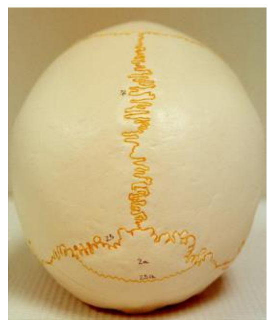
2. Identify points in a structure where flexible or fixed joints are required, and evaluate the appropriateness of different types of joints for the particular application. (Pg. 313 – 318 in text)

A structural joint is the space or opening between two or more adjoining surfaces. It is the gap or space created when two building materials come together, such as where two pieces of molding join or where the bathtub and bathroom wall meet.
Joints can be fixed or flexible.

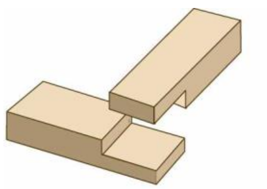
Fixed joints don't allow for any movement. The job of fixed joint is to hold adjoining pieces together so that they maintain a specific shape.



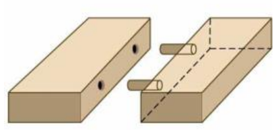
These tent poles have fixed joints



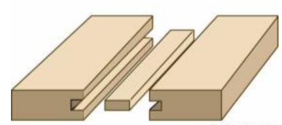
Human skull joints are fixed



End-lap fixed joint

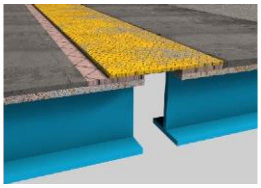


Doweled fixed joint



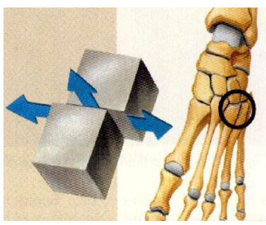
Splined fixed joint

Flexible or mobile joints allow for movement.

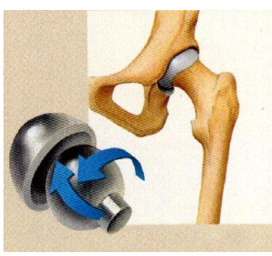


Expansion (or contraction) joints create a break or space in a structure to allow for thermal expansion and contraction of the materials used in the structure.

Hinge joints allow for movement in one plane. The hinge joints of the elbow and knee, for example, bend up and down. Doors are on hinge joints as are CD cases.



Gliding joints are two flat-surfaces that slide over one another. Gliding joints, such as those in the wrist and the foot, provide for limited movement. Drawers are gliding joints.



Ball-and-socket joints allow for the greatest range of motion. The ball-and-socket joints of the shoulder and hip, for example, can rotate in a complete circle. A simple rear-view mirror has four ball and socket joints.

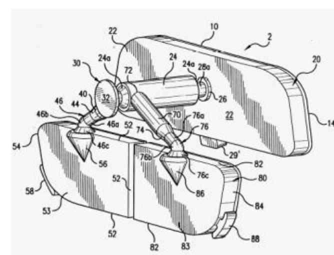
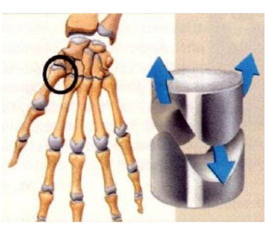


FIG.4



Saddle joints are where a concave and convex surface fit together allowing for movement but also stability. The thumb is a saddle joint, as are many building joints such as log cabins.

3. **Compare structural properties of different materials, including natural materials and synthetics.** (Pg. 308 – 312 in text)

Properties of materials:

- A property is a quality or characteristic that belongs to something.
- All materials have certain qualities and characteristics that can be defined and tested.

Physical Properties of Materials	Description
compressive strength	Will it snap when compressed (brittle) or will in be more elastic and rebound?
tensile strength	Can you stretch it without it breaking
density	How heavy is it?
hardness	Will it be able to stand up to wear?
resistance to heat or fire	Will it be able to withstand high temperatures?
Resistance to water	Will it be waterproof?

Other considerations when choosing materials include aesthetics (appearance), availability of products, monetary cost, and environmental safety (including recycling)

Materials we use to build structures must be strong in tension, in compression, or both. Steel, an alloy of iron with small amounts of carbon, is very common in construction. Steel wires bundled together to make suspension bridge cables are one material strong in tension. A steel cable one centimetre in diameter can support 8,000 kilograms--the weight of two full-grown Indian elephants!
Stone would not be a good choice for a tension structure. Stone is, however, strong in compression. Think of the Egyptian pyramids, which are made of stone blocks, some weighing over a tonne (1000kg). The blocks on the bottom support the weight of the upper blocks. The fact stone is strong in compression but weak in tension actually helped the Egyptians cut the huge limestone blocks. They drove wooden wedges into the limestone. The wedges were then soaked with water until they swelled up and split the limestone. The Egyptians used the strengths and weaknesses of stone to their advantage. Pretty smart!

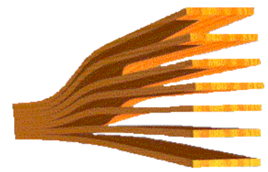
What if we mix two materials, one strong in compression and one strong in tension? Embedding steel rods into concrete makes reinforced concrete, a material stronger in tension than ordinary concrete.

D. **Demonstrate and describe processes used in developing, evaluating and improving structures that will meet human needs with a margin of safety.**

1. **Demonstrate and describe methods to increase the strength of materials through changes in design.** (Pg. 300 – 303, 329 – 330 in text)

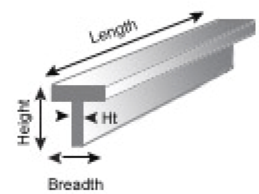
Materials are commonly strengthened through three methods:

- Corrugating – creating wave shapes, or ridges, that are pressed into a sheet of material that has been softened. This material is then sandwiched between flat sheets of material to form a corrugated structure which is much stronger that flat material.



- Laminating – making material stronger by putting several thin sheets together to form one solid piece.
- Combining – certain materials are stronger when they are combined together. For example, steel is made from iron and carbon. It is stronger and more flexible that either of the original materials. This is called an alloy.

Beams:



A beam is a structural member, usually long and narrow, which supports loads primarily by its internal resistance to bending. The principal structural materials for beams are: steel, light alloy, timber, reinforced concrete or pre-stressed concrete. They can be many different shapes (flat, I-beam, T-beam (as shown), U-beam, etc.)

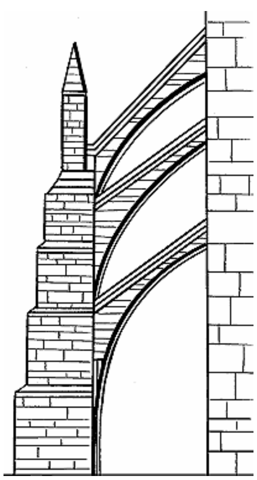
Trusses:

A truss is an assembly of interconnected triangles most commonly used to strengthen bridge decks, which are subject to great stress. Horizontal bars, called chords, run along the top and bottom of the length of the deck, usually on both sides. These upper and lower chords are joined by diagonal and sometimes vertical braces -- called struts (compression) and ties (tension), respectively -- which create triangular configuration. A triangle is a particularly rigid shape that will not bend, twist, or otherwise deform because a force pulling on one of the three sides is balanced by pushing forces on the other two sides. Trusses derive their strength from triangles: the bigger its triangles, the more strength and rigidity a truss will provide.

Trusses have many advantages over girders and solid beams, which can also provide stiffness to a structure. A truss is especially useful because its construction is so lightweight. Since the individual pieces are small, trusses can be built even in places where heavy equipment cannot be used. Trusses can support heavy loads over long spans and can be incorporated into almost any bridge design. Trusses create a hollow skeletal structure, so that a roadway may pass either over or through it, leaving room below. In addition, a truss offers a minimum of surface area on which wind can act, thereby diminishing another force that could potentially destabilize a structure.

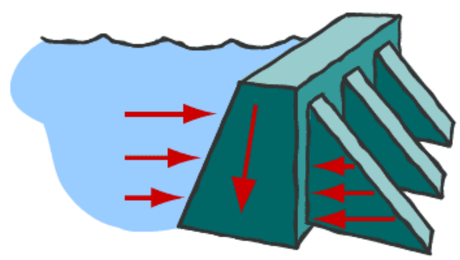
Buttresses:

A buttress is a support, usually of stone or brick that supports a structural, load-bearing wall. It can be separated (a flying buttress) or can be attached directly to the wall.



Flying buttress

Natural tree buttress



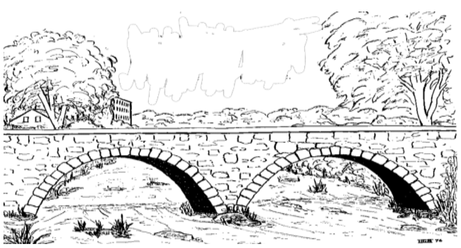
Dam buttress

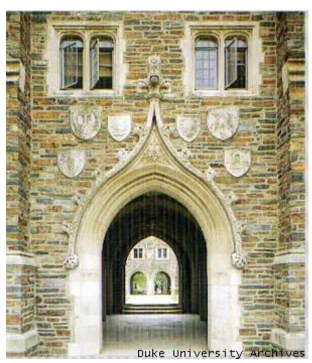
Column or Pillar:

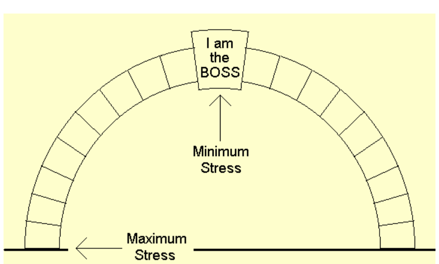
A column or pillar is a tall, cylindrical (usually) vertical upright that is used to support a structure.

Arch:

The arch, a curved shape spanning an opening, is one of the oldest means of spanning rivers and forming the roofs of large buildings. The arch form dominates the early history of building as without the availability of a material capable of taking significant tensile stresses, a predominantly compressive system was the only means of forming large spans -- hence early structural and architectural forms were primarily based on columns, arches, and domes. With the coming of steel and the ability to cast in concrete, there was a revolution in arch design with a dramatic increase in possible span.



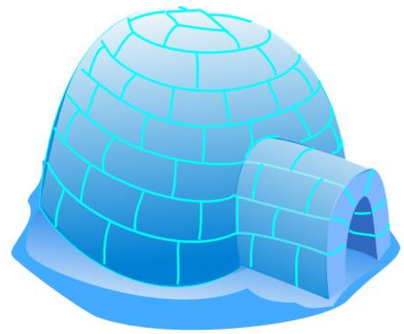




The keystone is the central wedge at the top of an arch.

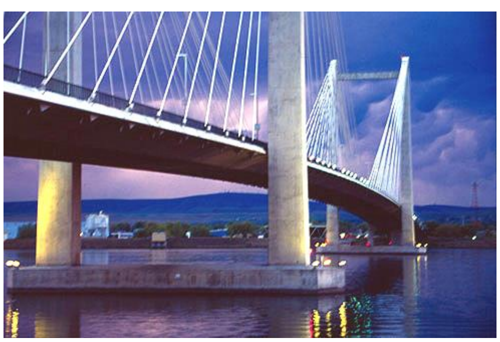
Dome:

A dome is a concave shape whose distinguishing characteristic is that the concavity faces downward. Geodesic domes are especially strong structures. The geodesics intersect to form triangular elements that create local triangular rigidity and distribute the stress. It is the only man made structure that gets stronger as it increases in size. Of all known structures, a geodesic dome has the highest ratio of enclosed volume to weight.



Cables:

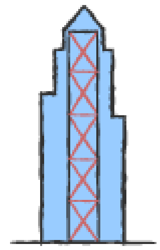
Cable is a structural element formed from steel wire bound in strands; the suspending element in a bridge; the supporting element in some dome roofs. A cable-stayed bridge is a bridge in which the roadway deck is suspended from cables anchored to one or more towers.



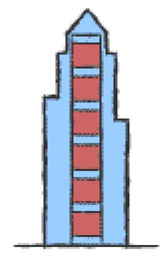
2. **Identify environmental factors that may affect the stability and safety of a structure, and describe how these factors are taken into account.** (Pg. 290 – 293, 326-327 in text)

Forces of nature can be very powerful and must be considered when building structures.

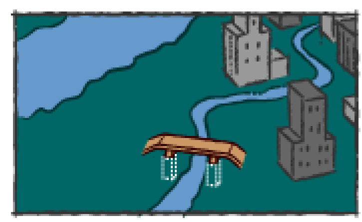
Wind: Tall buildings and bridges are often braced against wind damage.



Earthquake: Buildings can be made more earthquake resistant by putting a strong central spine made of concrete that won't sway. Buildings should never be built on soft sediment that acts like a liquid during an earthquake.

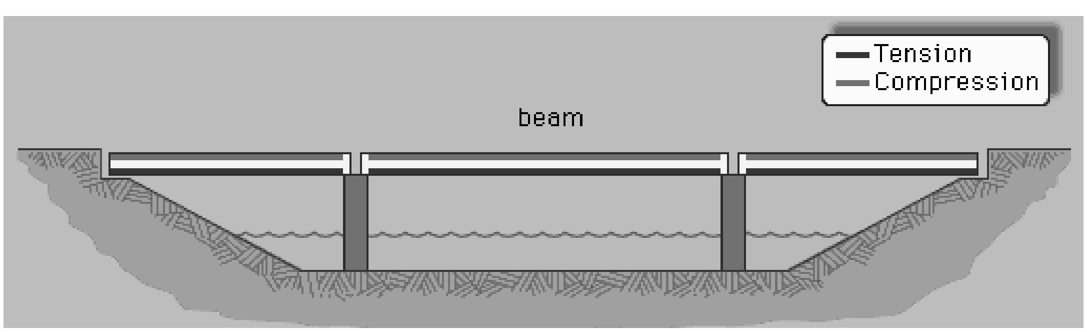


Water: The power of water is incredible. Just ask Hurricane Katrina and tsunami survivors. Securing bridges and buildings with deep piers (columns buried underground) will help stabilize the structures against the force of water.



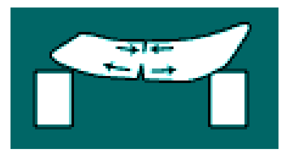
Beam Bridge:

A beam bridge is the simplest and most inexpensive kind of bridge. According to Craig Finley of Finley/McNary Engineering, "they're basically the vanillas of the bridge world." In its most basic form, a beam bridge consists of a horizontal beam that is supported at each end by piers. The weight of the beam pushes straight down on the piers. The beam itself must be strong so that it doesn't bend under its own weight and the added weight of crossing traffic. When a load pushes down on the beam, the beam's top edge is pushed together (compression) while the bottom edge is stretched (tension).



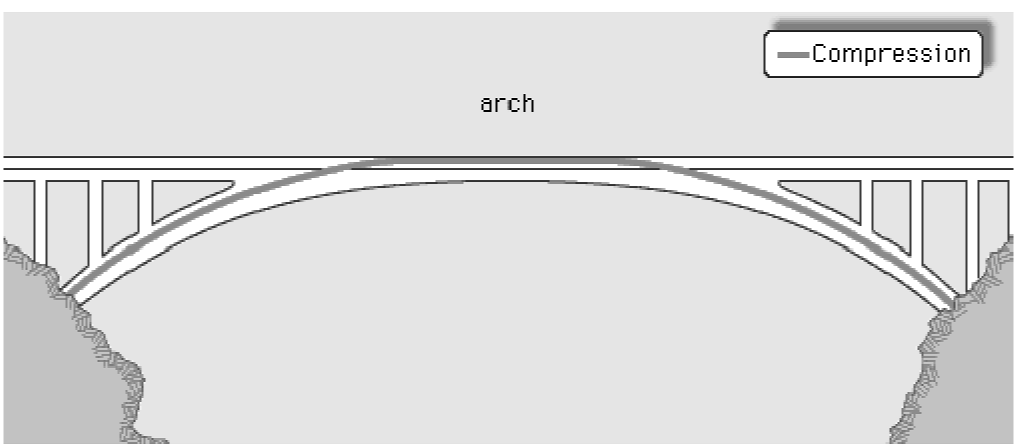
Pre-stressed concrete is an ideal material for beam bridge construction; the concrete withstands the forces of compression well and the steel rods imbedded within resist the forces of tension. Pre-stressed concrete also tends to be one of the least expensive materials in construction. But even the best materials can't compensate for the beam bridge's biggest limitation: its length. The farther apart its supports, the weaker a beam bridge gets. As a result, beam bridges rarely span more than 80m (250 feet). This doesn't mean beam bridges aren't used to cross great distances -- it only means that they must be daisy-chained together, creating what's known in the bridge world as a "continuous span."

Try this:
Take a flat eraser or a small sponge and slice a shallow notch across the top and bottom. Create a beam bridge by supporting each end of the eraser (or sponge) with a stack of books. Press down on the center of the bridge. What happens to the top and bottom notches? Notice how the top notch squeezes together in compression, while the bottom notch spreads apart under tension.



Arch Bridge:

An arch bridge has a semicircular structure with supports at both ends. Because the only force acting on the bridge is compression, arch bridges can support heavy loads easily and are longer than beam bridges. When supporting its own weight and the weight of crossing traffic, every part of the arch is under compression. For this reason, arch bridges must be made of materials that are strong under compression. Arch bridges usually end in a large abutment (part of a structure which supports the end of a span or accepts the thrust of an arch). The stronger the abutment, the stronger the bridge.



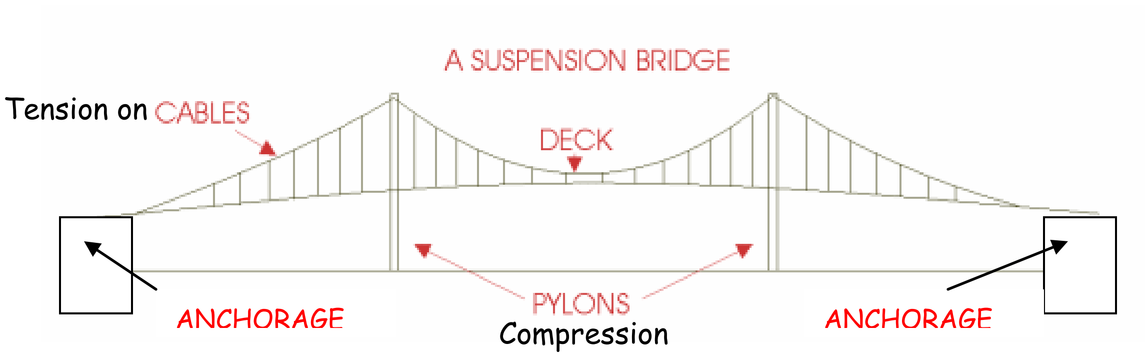
Try this:

Cut a strip of cardboard that's about one inch by 11 inches. Gently bend the strip so that it has a curve. Position the cardboard on a table so that it resembles an arch. Press down on the center of the arch. What happens to the ends of the cardboard?

Next, place a stack of books at each end of the arch. Press again. Now what happens? Notice how the stacks of books act as abutments, keeping the ends of the arch from spreading apart.

Suspension Bridge:

Aesthetic, light, and strong, suspension bridges can span distances from 2 500m (7 000 feet) — far longer than any other kind of bridge. They also tend to be the most expensive to build. True to its name, a suspension bridge suspends the roadway from huge main cables, which extend from one end of the bridge to the other. These cables rest on top of high towers called pylons and are secured at each end to an anchorage. The towers enable the main cables to be draped over long distances. Most of the weight of the bridge is carried by the cables to the anchorages, which are imbedded in either solid rock or massive concrete blocks. Inside the anchorages, the cables are spread over a large area to evenly distribute the load and to prevent the cables from breaking free.

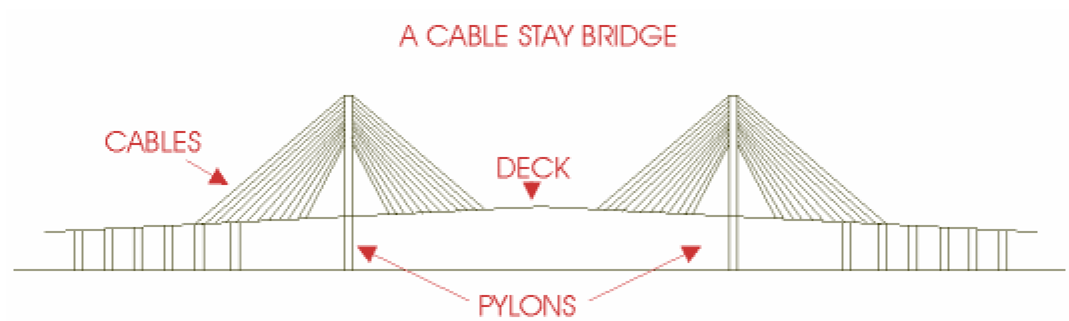


Try this:

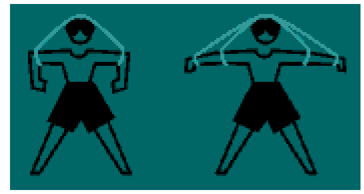
Tie two loops of string around the tops of two hard cover books of similar size. Tie a third piece of string to each loop so that it hangs loosely between the books. Press down on the center string. What happens? Next, stand two books about 10 inches apart. Put a stack of heavy books on one end of string to secure it to the table. Then pass the string over each book (letting some string hang loosely between the books). Place a second stack of books on the other end of the string. Press again on the center of the string. What happens? Notice how the anchorages (stacks of books) help to stabilize the bridge. Tie two loops of string around the tops of two hard cover books of similar size. Tie a third piece of string to each loop so that it hangs loosely between the books. Press down on the center string. What happens?

Cable-Stayed Bridge:

Cable-stayed bridges may look similar to suspensions bridges — both have roadways that hang from cables and both have towers. But the two bridges support the load of the roadway in very different ways. The difference lies in how the cables are connected to the towers. In suspension bridges, the cables ride freely across the towers, transmitting the load to the anchorages at either end. In cable-stayed bridges, the cables are attached to the towers, which alone bear the load.



Try This:
Stand up and hold your arms out horizontally at each side. Imagine that your arms are a bridge, and your head is a tower in the middle. In this position, your muscles are holding up your arms. Try making cable-stays to support your arms. Take a piece of rope (about five feet long), and have a partner tie each end of the rope to each of your elbows. Then lay the middle of the rope on top of your head. The rope acts as a cable-stayed and holds your elbows up.



Have your partner tie a second piece of rope (about 6 feet long) to each wrist. Lay the second rope over your head. You now have two cable-stayeds. Where do you feel a pushing force, or compression? Notice how the cable-stayeds transfer the load of the bridge (your arms) to the tower (your head).

Cantilever Bridge:

Cantilever bridges are a modified form of beam bridge, with the support being placed not at the end, but somewhere in the middle of the span. A cantilever is a structure or beam that is unsupported at one end but supported at the other, like diving boards. This configuration made longer spans possible and wider clearance beneath.

Cantilever Bridge

Natural cantilever rock

Trusses are used to stiffen and support a bridge by distributing the loads and forces acting upon the bridge based on the positions of the vertical, horizontal and diagonal chords. They are based on triangular configurations. How those chords are arranged identifies the type of truss. Trusses are also used on cantilever bridges and to support the decks in suspension bridges. Trusses are "through trusses" when the truss is above the deck, and "deck trusses" when they are underneath, supporting the deck.