

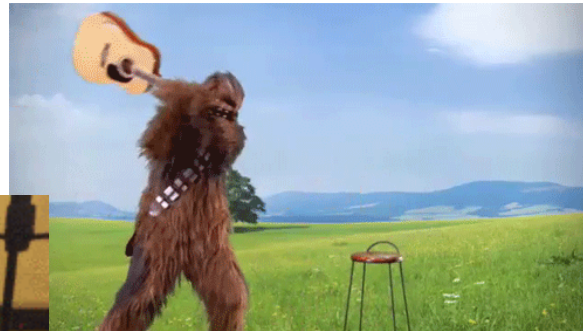
Designing To Withstand Failure



Causes of Structural Failure

1. Compression
2. Tension
3. Torsion
4. Shear
5. Levers

Structures will fail if they are not able to resist these forces.





Earthquakes Create Violent Shear Forces

How do we design structures so that this doesn't happen?

1. Tuned Mass Dampers

2. Base Isolation

Earthquakes Create Tremendous Shear Forces

- Solution → Tuned Mass Dampers
- Masses that hang inside the building.
- Absorb Swaying Motions. How?
- When building sways one way, the damper sways in the other direction thereby cancelling the motion out.
- Great for tall skyscrapers. Not used in shorter buildings.



Tuned Mass Damper Must Be Tuned Juust Right!

- Too heavy → will crush the building it hangs in.
- Too light → it won't do anything.
- Too short → won't swing enough.
- Too long → will swing too much (that's a bad thing)
- Must be tuned juuuuust right to work properly.
- A lot of math and testing is involved when tuning a damper.

Dampers in Action



<https://www.youtube.com/watch?v=3c5U4CwVz5c>



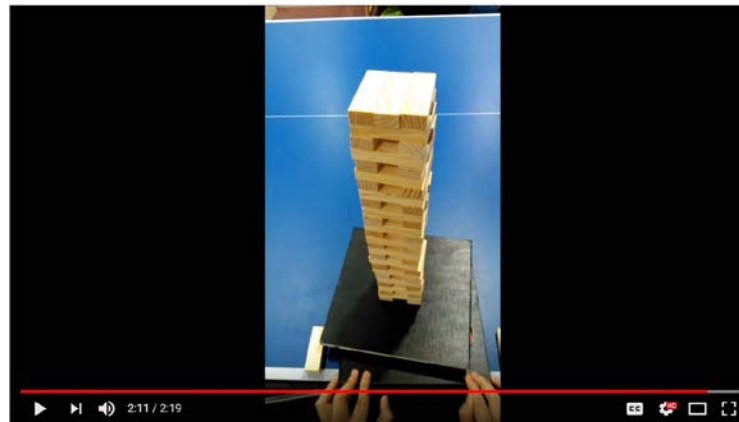
https://www.youtube.com/watch?v=ohKqE_mwMmo

Base Isolation → For Buildings 'shorter than 10 stories'.

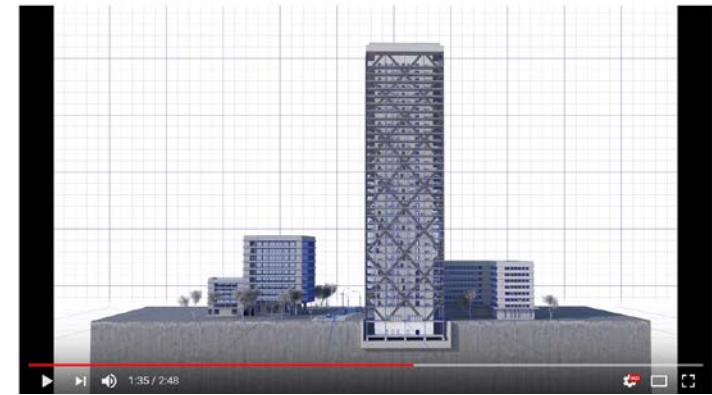
- Disconnects the base of the structure from the shaking earth using flexible materials move in the opposite direction of the shaking.



<https://www.youtube.com/watch?v=fw0rgJUtxiM>



<https://www.youtube.com/watch?v=m14FlqowVaM>



<https://www.youtube.com/watch?v=l1NWtVaTg7I>



<https://www.youtube.com/watch?v=9N8iQ9Ch8nw>

Levers Can Easily Fail!

- A lever is anything that looks like a handle.
- Flagpoles, door knobs, the CN tower, and even your stair rail all act as levers because they look like long handles.
- The longer the lever, the less force is needed to rip the lever off.
- So tall towers and tall flag poles are at greater risk than shorter ones.
- Levers must be secured by being bolted down very well. Bolts must be checked regularly in case they get loose.

More Examples of Levers

- The longer the lever, the easier it is to rip out the joint.
- The base of a lever must be secured very well.



- Stair Rails are levers. Why?



- Don't hang off the door knob
- Plz and thank you.



- Criminals love levers.
- The want levers to cause a structure to fail.

Epic Lever Fails

- The wind striking the CN tower and the flag pole is enough to rip it out of the ground if it is not maintained well enough at the base.

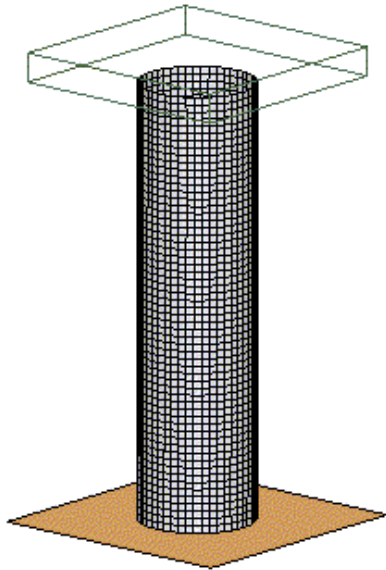


Resisting Failure → Definitions

- **Compression Strength** → The maximum compression force a structure can handle before failing.
- **Tension Strength** → The maximum tension force a structure can handle before failing.
- **Torsion Strength** → The maximum torsion force a structure can handle before failing.
- **Shear Strength** → The maximum shear force a structure can handle before failing.

Buckling → Compressive Failure

- Buckling is when a structure crumples up due to compressive forces.



Buckling...Misunderstood!

- Buckling is good in times of a car crash, because the metal will absorb a lot of the impact.
- There was a story going around regarding cars that had front hoods made of carbon fiber. The rumor was that carbon fiber is so strong that instead of buckling in a head on collision, the hood would blast through the windshield and decapitate the driver and passenger.
- The grass under your feet buckles every time you step on it thereby absorbing some of the impact.
- Accordions buckle when you compress it. This buckling helps push air out to create musical sounds.
- Buckling is bad if it happens to a boat as it gets compressed by the water smashing into it.
- Buckling is bad if a rocket crumbles as it experiences tremendous forces from the air it flies through.
- Can you think of any more examples of when buckling is a good thing and when it is a bad thing?

Torsion...Misunderstood!

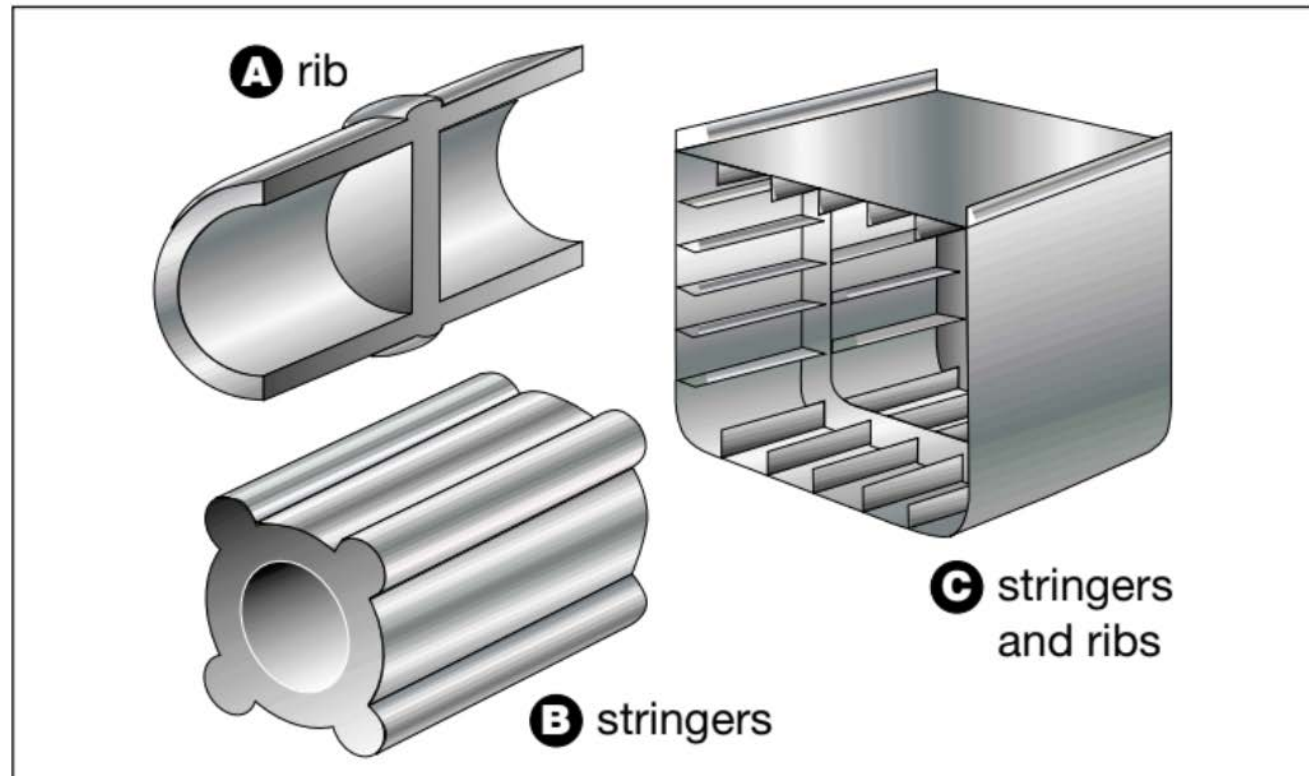
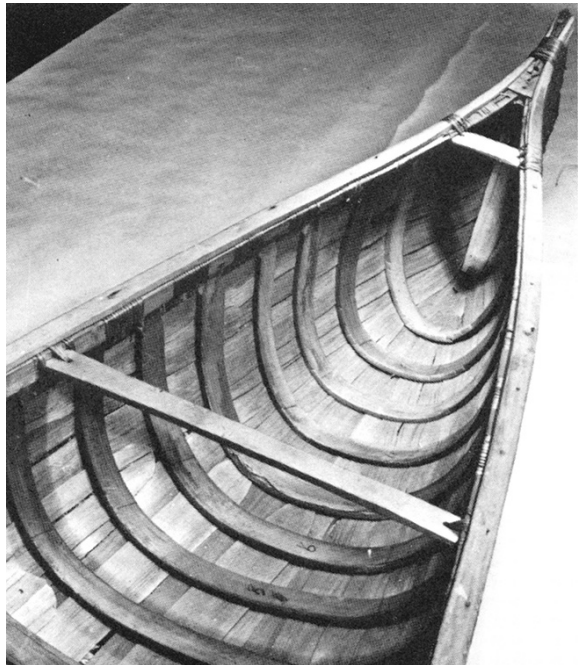
- Torsion can be good and it can be bad.
- A piece of thread is pretty weak. However, if you twist a bunch of threads together (i.e torsion) then you can make strong rope. If you overstretch threads, then the bundle shortens and becomes very stretchy. This is how stretchy fabrics can be made.
- Twisting your hair into a braid strengthens the bundle of hair.
- Torsion applied on your knee, however, is a really bad thing.
- Can you think of any more examples where torsion is both a good thing and a bad thing?

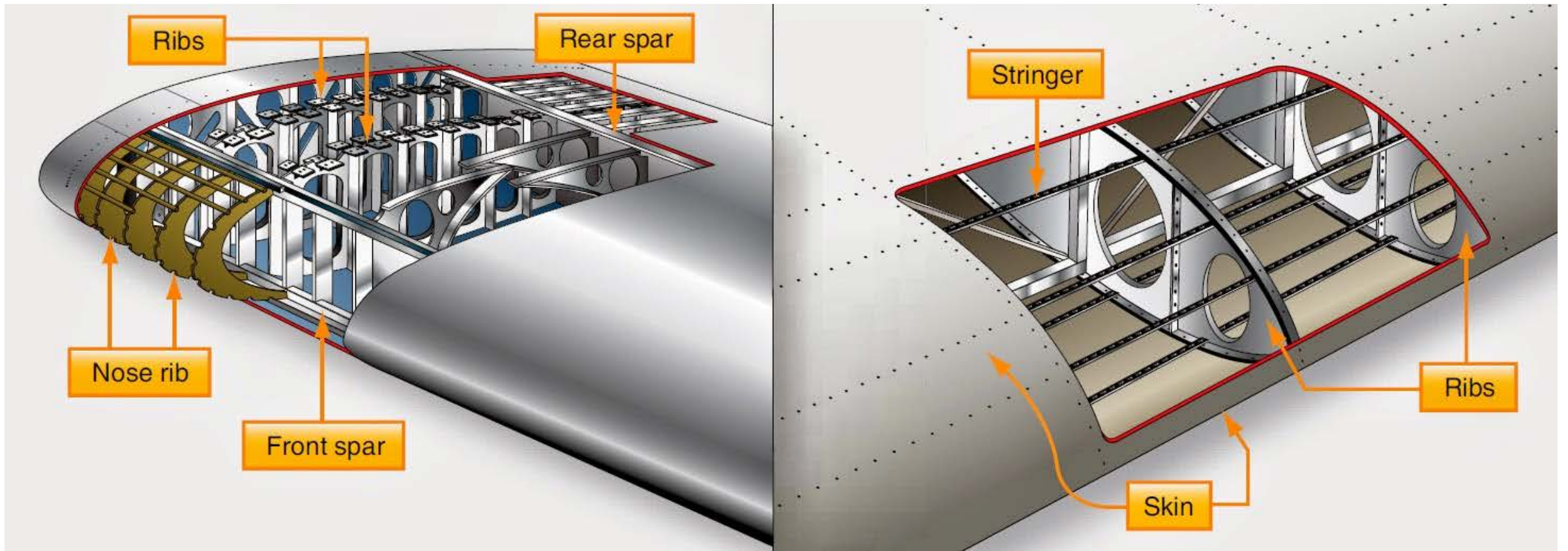
Shear...Misunderstood!

- Shear forces are necessary inside of an engine in a complicated process that eventually get the wheels to turn.
- Shear forces though were a big problem in the early years of train tracks.
- When the liquid iron was molded into the shape of railroad tracks and then cooled down to solidify, microscopic cracks would form in the metal.
- Over time, shear forces from the train would cause the cracks to grow larger until they shattered.
- Engineers realized that if the liquid iron tracks were allowed to cool much slower, the cracks did not form. Problem solved.

Preventing Buckling, Bending, Shear and Torsion Failure?

- We call in the ribs and stringers!
- Ribs/Stringers prevent thin shells from failing under certain forces.
- Often times they are found hidden on the inside of shell structures such as canoes, boats, and rockets.





Ribs & Stringers Inside an Aircraft Wing

Train Wheels Used To Fall Off. Why?

- 200 years ago, engineers did not know why this happened. Indeed, they did manufacture the train axles so that they were stronger than necessary. So what gives?
- Then 150 years ago, engineers realized that metal weakens over time when torsion and bending is applied to it.
- Not convinced? Take a paper clip and bend it back and forth a few times. What happens.
- This is called metal fatigue.
- Can you think of other structures that experience metal fatigue?



Did Metal Fatigue and Shear Force Contribute to the 1986 Roller Coaster Crash at WEM?



Write down the major factors that caused the roller coaster crash.

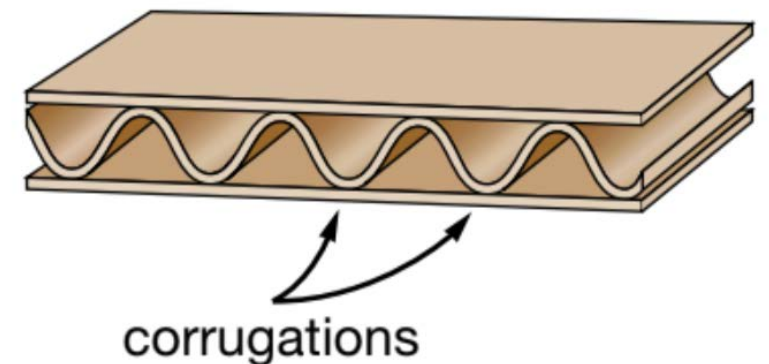
Build Strong, But Build Light!

- Its important to build strong structures that are also very light.
- This allows us to save money and resources, thereby reducing our ecological footprint, while still building something strong.



Cardboard---Strong, but Light

- Corrugations
- Cardboard folded into waves (baby triangles) and sandwiched in between 2 thin sheets of cardboard.
- Corrugations makes the cardboard super-strong while reducing the amount of material needed, thereby making the cardboard lighter.



Bones---Strong, but Light

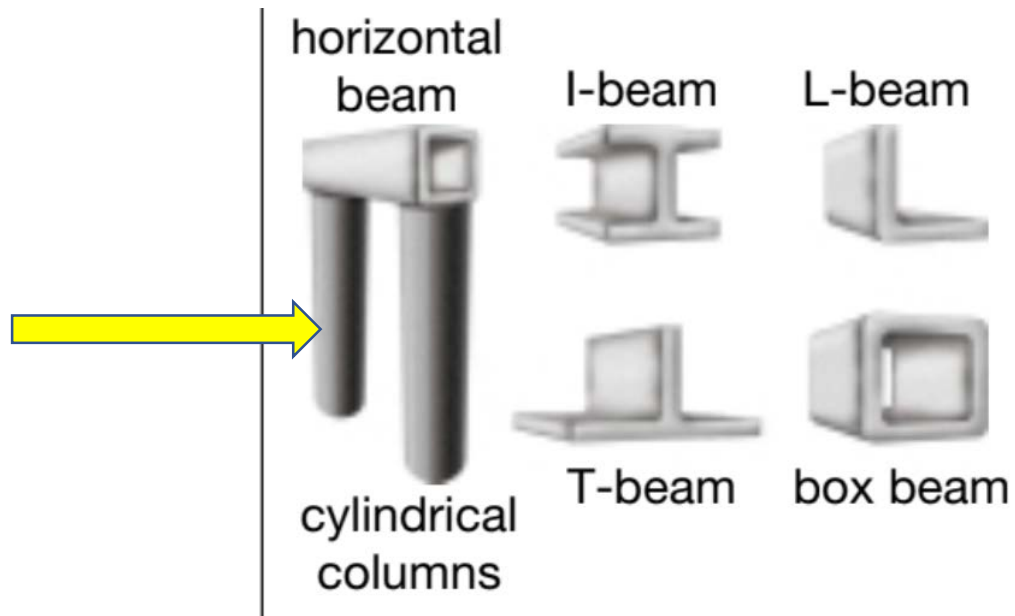
- Having Heavy bones would suck!
- Imagine trying to walk or run if your bones were heavy.
- All of the bones in your body only weigh about 7 to 8 pounds.
- To get around this problem, Allah designed our bones as hollow shells and stuffed them with a super-light, spongy material called bone marrow.



Beams—Strong, but Light!

- Instead of making heavy, bulky support beams, beams are often hollowed out or cut out into designs to remove some metal, thereby making the beams lighter.
- The result is that you get beams that are super-strong shells, but super- light.

Cylindrical columns are often hollowed out. Because they are round, they are stronger than all of those other beam designs.



Frames → Strong and Light

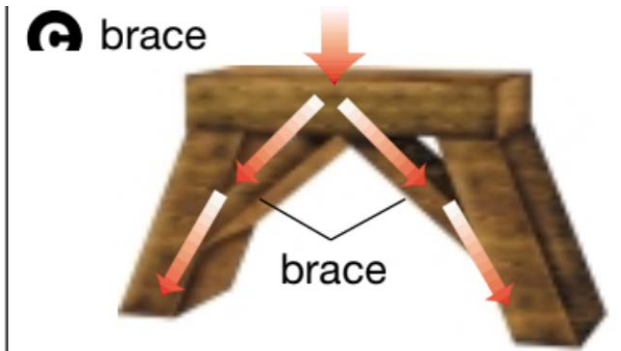
- Yes they are....Thanks to braces.
- Braces connect different parts of a frame that would otherwise spread apart when a force is applied.

Check out the braces grabbing the legs of this chair. Without the braces, the legs would do the splits.



Some braces are hidden

A V-Brace will direct the compressive forces away from the structure and into the ground.



Frames → Strong, but Light

- Look at how these triangular braces are used on the bridge.
- We call these types of braces, Trusses.
- They strengthen the entire bridge while reducing the amount of metal used. Often they are either hollow box beams, or I, T, or L beams.



How can you rebuild this table to avoid the sag?



Arches---Strong! Sometimes Light!

- The central stone is called the keystone.
- It is shaped like a wedge.
- As it slips further down between the next two stones, the keystone presses harder against the two beside it.
- This shape directs the forces along the stones and down to the ground as shown by the arrows.
- Domes and shell structures are based on the same concept.



Riddle: What is stronger? One thick piece of wood or a many thinner pieces of wood glued together?

- The Answer: The thinner pieces of wood glued together are going to be a lot stronger than a big chunk of wood of equal thickness.
- This is called a **lamination**.
- We laminate plywood, linoleum tiles and even laminate paper with a layer of thin plastic to strengthen it.

Close-up of 1 sheet of plywood. Look at the thin layers laminated Together. This helps strengthen the overall wood.



What To Consider Before Building!

1. Aesthetics
2. Cost
3. Environmental Impact
4. Safety
5. Margin of Safety

1. Aesthetics

- How attractive is your structure?
- Structures must look good if they are to be used. Think smartphones, clothing, cars, and just about anything else that you buy.
- It must look good.



2. Cost

- You can reduce costs by purchasing the cheapest material.
- The problem with that is that those materials may not last as long or require more maintenance which will ultimately increase your costs.
- More expensive materials may cost more, but last longer and require less maintenance.
- You must find the right balance.



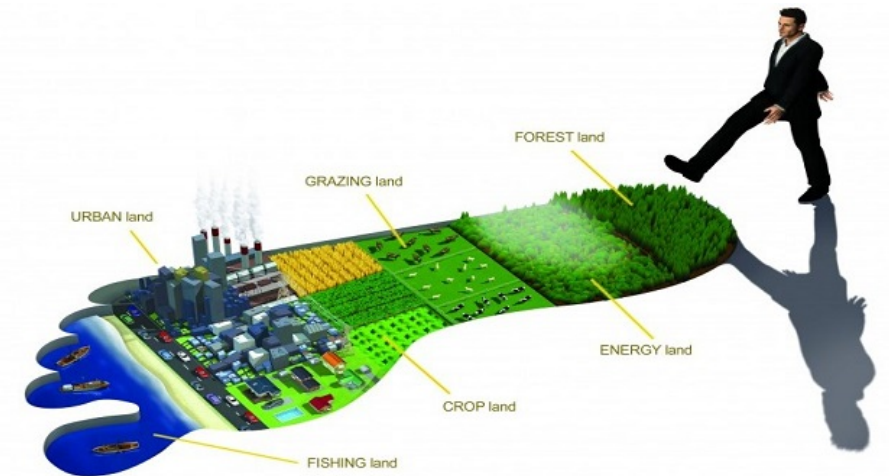
Cost Continued

Builders need to avoid waste when cutting large pieces of building materials. How can you make one straight vertical cut and one straight horizontal cut to divide the cross shape below into four pieces that can be reassembled into a square?



3. Environmental Impact

- Will you be destroying a wetland or forest when building your structure?
- Are you using resources that came from an endangered habitat?
- Did you have to exploit a lot of the earth's resources to acquire these resources (think back to ecological footprint).
- How much water is used in its manufacture? Can you minimize it?



4. Safety

- Is there a chance someone will get injured while using your structure?
- Will it hurt their hearing, vision, skin, bones, tongue, etc.
- Are there ways to avoid these safety issues?



5. Margin of Safety

- If you are asked to build an elevator that can carry 1000 pounds, build it so that it supports 2000 pounds, but write 1000 pound limit on the warning tag.
- This is called a margin of safety. It is a white lie designed to keep people within the limits.
- If you designed the elevator to hold exactly 1000 pounds and exactly 1000 pounds came onto the elevator, there is a chance that the cable will snap.
- In other words, always design structures to be stronger than you say it is. Leave an extra “Margin of Safety”.

Joints?

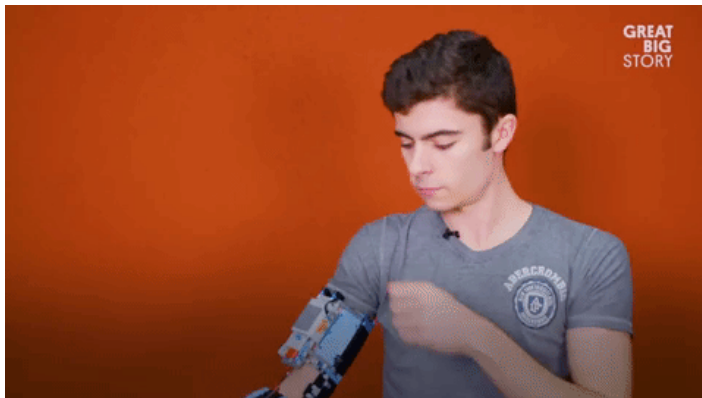
Most structures require materials to be joined together.

Fun Fact: Joints are the weakest part of a structure. So build them well.

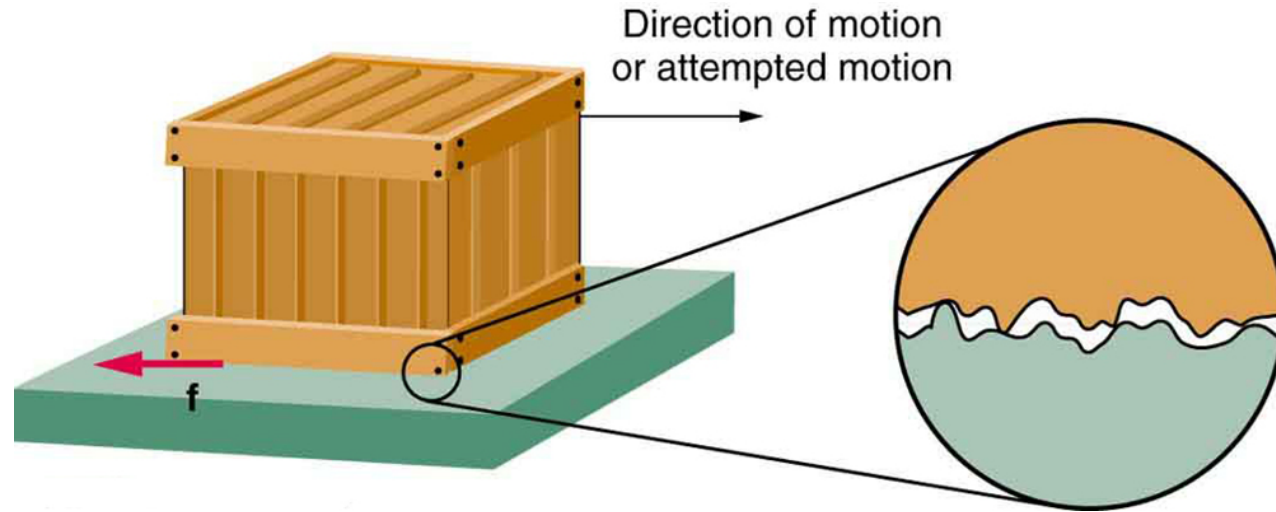
2 types

Mobile Joints

Rigid Joints



Friction is the Force that Joins Things Together.



- Smooth objects are not really smooth.
- Under a microscope all surfaces are jagged.
- These surfaces lock together.
- We call this friction. Friction resists motion.
- Friction is what causes a nail or screw to hold 2 pieces of wood together.
- Friction is also what causes you to sit in one spot without sliding everywhere.



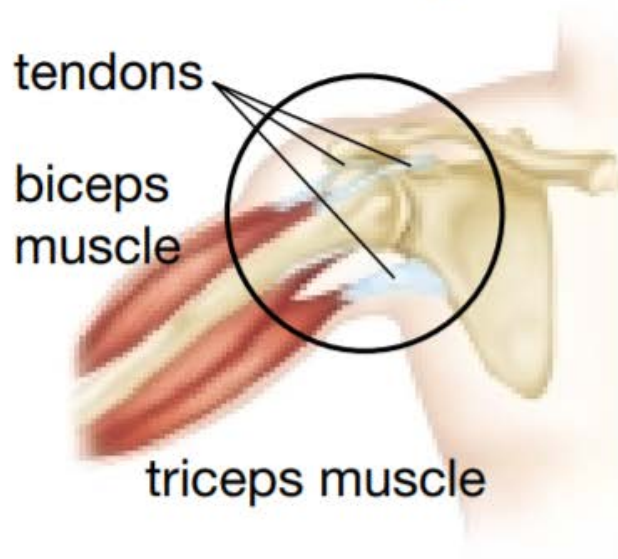
Which will join 2
wooden pieces
together?

1. Mobile Joints

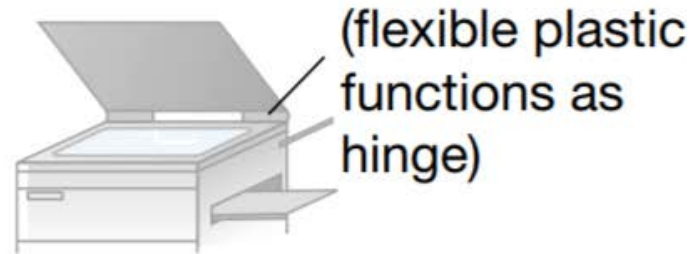
joints that allow 2 pieces to rotate and move



ball-and-socket joint



lid on photocopier



door hinge



trailer hitch



Rigid Joints

- 1. Fasteners**
- 2. interlocking shapes**
- 3. ties**
- 4. adhesives**
- 5. melted joints**



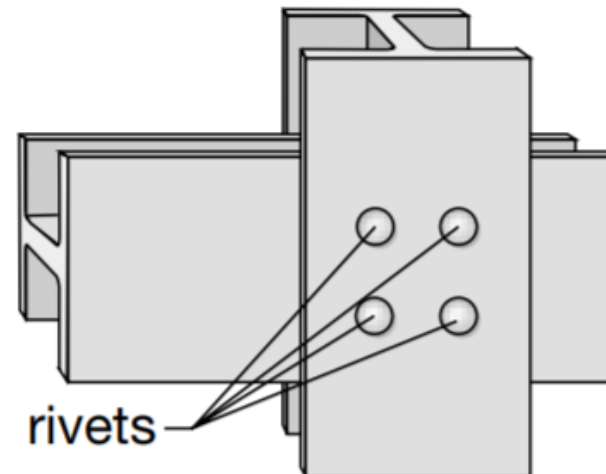
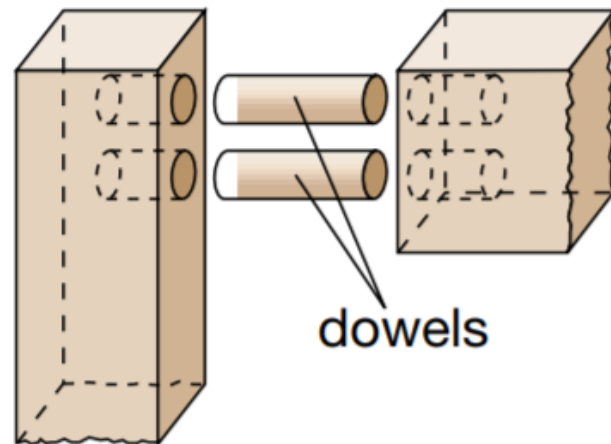
1. Fasteners (Rigid Joint)



Nails, bolts, screws, dowels, staples, paper clips.

Fasteners often make holes in the things that they hold together. A nail driven into a piece of wood can crack the wood.

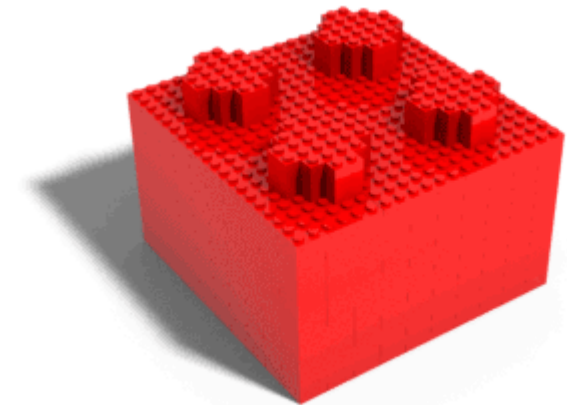
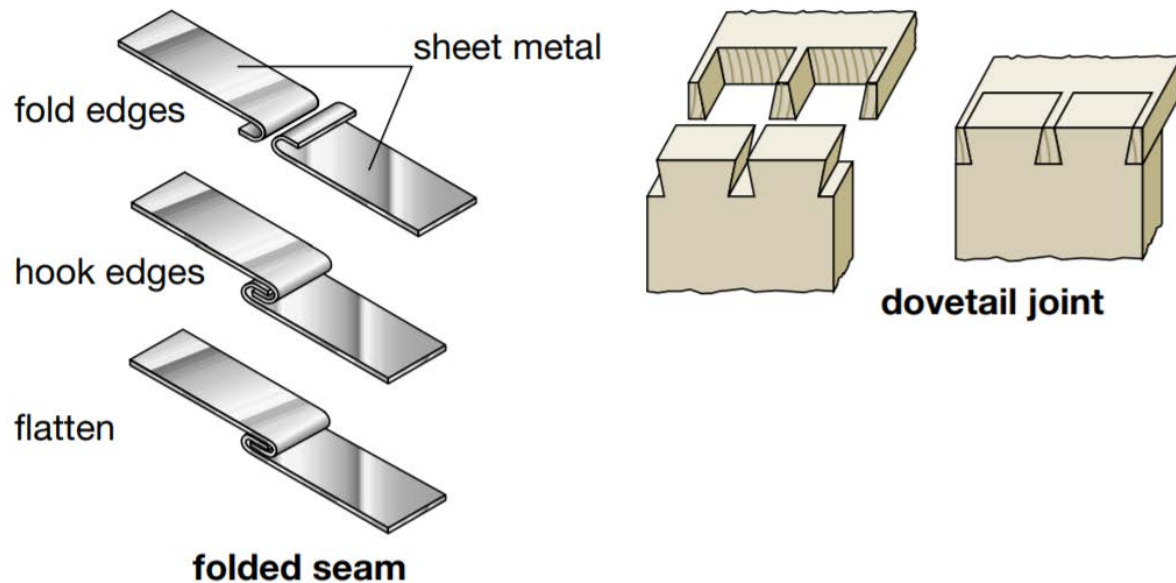
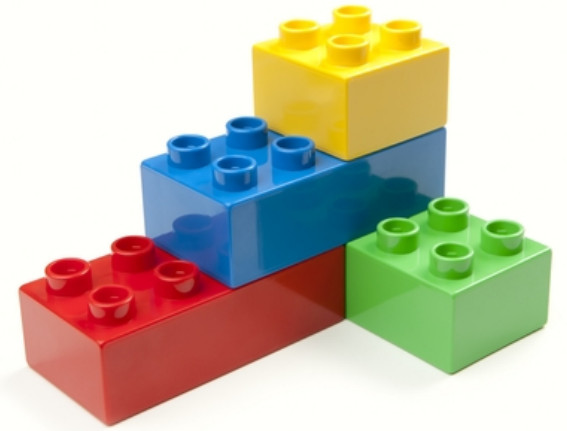
Other fasteners that use pre-drilled holes for dowels or bolts don't weaken the material as much, but they take a long time to make.



2. Interlocking Joints (Rigid Joint)

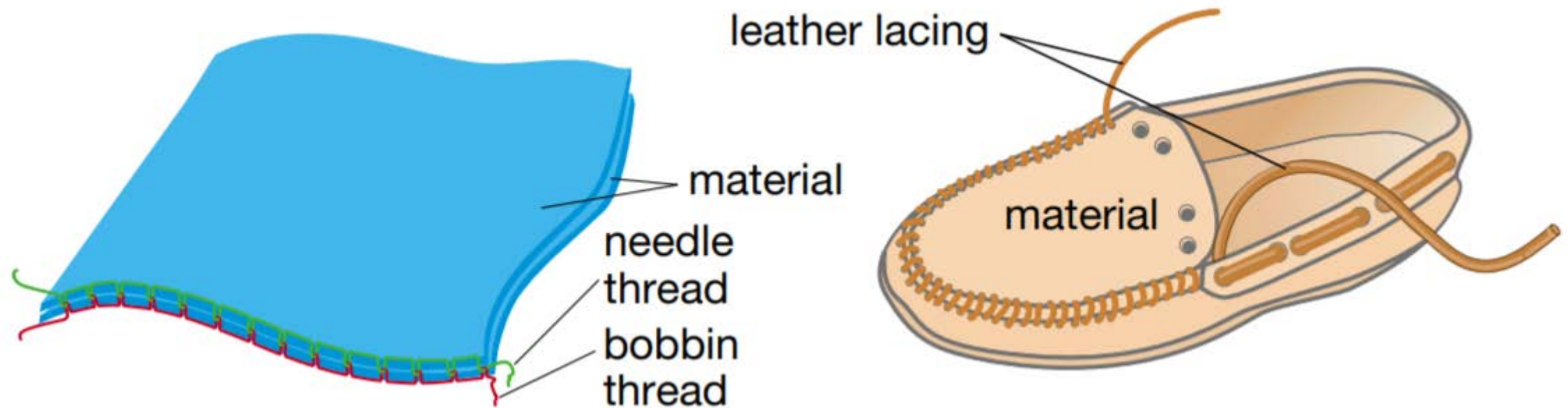
Think Legos

Pieces click together and are locked in place. Your drawers are like dovetail joints. Yes they slide up and down the joint, but they cannot rotate in the joint, so they are Rigid.



3. Ties(Rigid Joint)

Think Sewing threads together.



4. Adhesives (rigid joint)

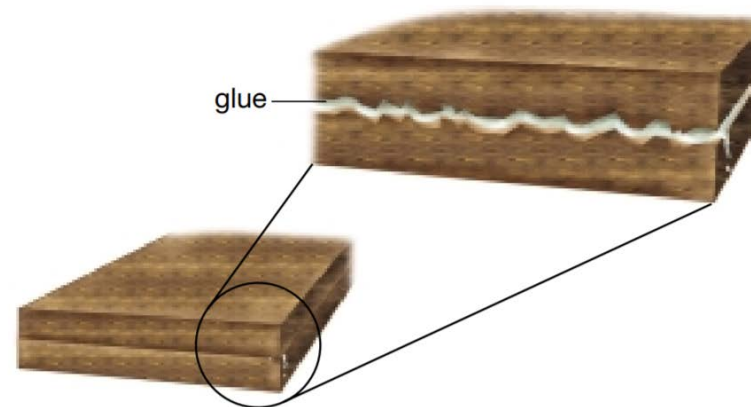
Think Glue & Tape

Thermosetting Glue: hardens as it cools (think glue gun)

Solvent Based Glue: hardens as it dries. (Think Elmer's White Glue)

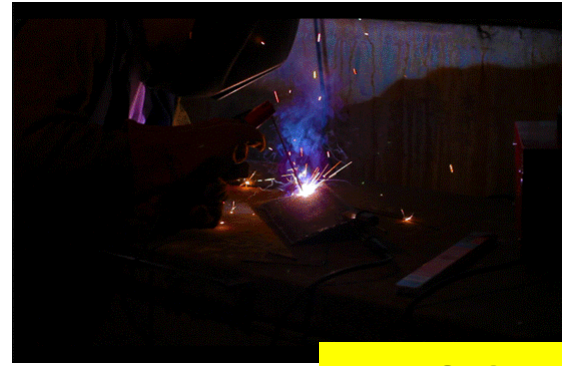
Solvent based glue: Hardens as it dries (think Elmer's glue). Typically stronger than thermosetting glue, but takes longer to dry.

Caution**** toxic smells.



5. Melting (rigid joint)

Welding vs Soldering

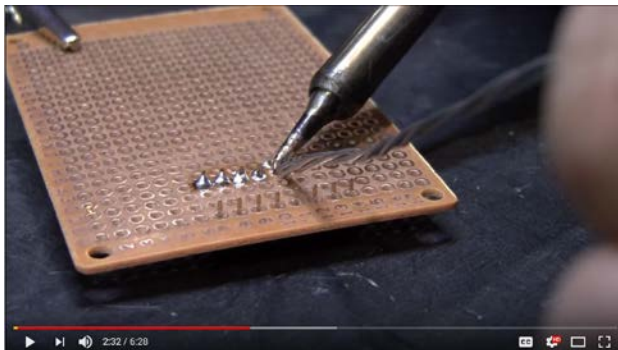


Welded Pipes



1. Welding: 2 metals are melted together. When they cool down, they become a joined unit.

2. Soldering: Another separate metal is melted and used to join 2 other metals together...kinda like chewing gum holding



Soldering

<https://www.youtube.com/watch?v=oqV2xU1fee8>





K relax...not quite!