External and Internal Forces

Measuring Forces

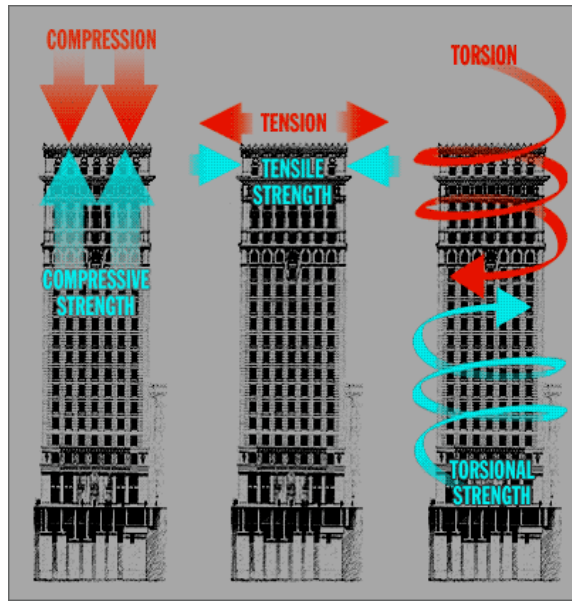
A **force** is a push or pull that tends to cause an object to change its movement or shape.

Magnitude, Direction, and Location

The actual effect of a force on a structure depends on:

- the *magnitude*, or size, of the force (the bigger the force's magnitude, the stronger it is and the more effect it will have on a structure)
- the *direction* of the force
- the *location* where the force is applied

When drawing forces, the force is represented by an arrow. The different sized arrows tell us a little about the magnitude, direction and location of the forces in a diagram.



The Newton

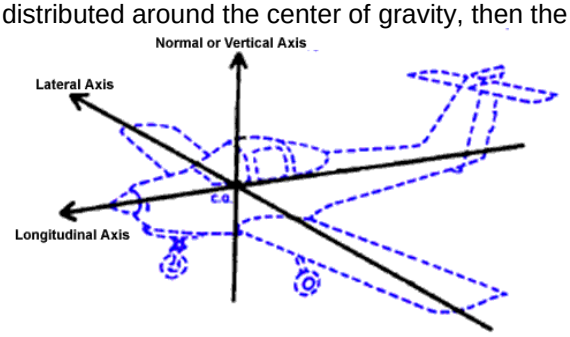
The standard unit for measuring force is called a **Newton** (N). One Newton is the amount of force needed to hold up a mass of 100g.

External Forces

External forces on structures are stresses that act on a structure from outside the structure. Gravity is one such force, acting on all things all the time. *Impact forces* (things that collide with the structure) are another type of live load. External forces produce internal forces, or stresses, within the materials from which the structure is made. These internal stresses can change the shape or size of a structure and is called deformation. This deformation can lead to repair of the damage to the structure, or failure of the structure.

Centre of Gravity

The center of gravity is the specific point where all of the mass of the structure is evenly distributed around. The force of gravity acts on all parts of the structure and if all parts are evenly distributed around the center of gravity, then the structure will be stable.



The Axes of an Airplane

Engineers need to locate the center of gravity of a structure in order to stabilize the structure. By locating the structure's center of gravity, an engineer can tell if the structure is stable or unbalanced.

Try this Virtual Lab

To increase the stability of a structure you can increase the width of the base compared to its height and move the base closer to the ground.

Symmetry
Symmetry is a balanced arrangement of mass occurring on opposite sides of a line or plane, or around a center or axis. The force of gravity on either side of the center point of this line is the same.

Load
The load is an external force on a structure.

Static and Dynamic Loads

- A ***static (dead) load*** is a permanent force, acting on a structure. This includes the weight of the structure itself and the non-moving parts it supports.
- A ***dynamic*** (*live**)*** ***load*** is a changing, or non-permanent force acting on a structure. This includes the force of the wind and the weight of things that are in, or on a structure.

Supporting the Load

Different kinds of structures are designed to withstand different loads and forces. Different bridges are built for different purposes.

Type of Bridge	
Beam Bridge	- most common bridge used - flat beam supported at each end
Truss Bridge	- lightweight, but strong bridge made of trusses (triangle-shaped frames) along its sides
Suspension Bridge	- hangs between two ends (towers) that hold it up. - smaller cables attach the roadway to the hanging cables
Arch Bridge	- is designed to withstand heavy loads. - Roman aqueducts are good examples of this type of bridge

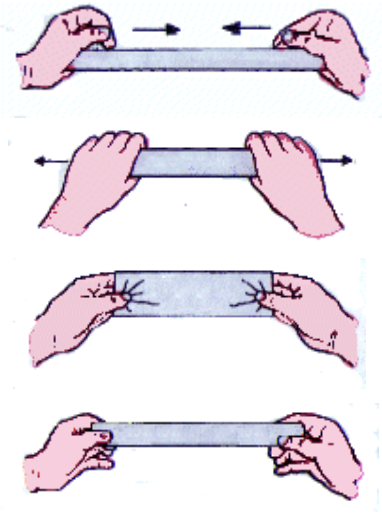
Measuring A Structure's Load Performance

How effectively a structure holds up its load is determined by performance requirements. Load performance is maximum weight. Other performance considerations include safety, cost, and effectiveness in meeting the purpose for which it was designed.

Comparing Performance
The performance of one structure can also be compared to that of another. This performance comparison is made by comparing *the load per unit of its own mass* for each structure.

Internal Forces

Compression, Tension, and Shear



Compression forces crush a material by squeezing it together. Compressive strength measures the largest compression force the material can withstand before it loses its shape or fails.

Tension forces stretch a material by pulling its ends apart Tensile strength measures the largest tension force the material can withstand before failing.

Shear forces bend or tear a material by pressing different parts in opposite directions at the same time.
Shear strength measures the largest shear force the material can withstand before it rips apart.

Torsion forces twist a material by turning the ends in opposite directions.
Torsion strength measures the largest torsion force the material can withstand and still spring back into its original shape.

Complementary Forces

A *bending force* is a combination of tension

and compression

Shear and torsion forces are also a combination of tension and compression

Designing Structures to Resist Forces and Maintain Stability

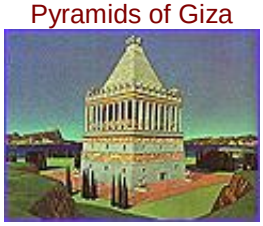
The Seven Wonders of the Ancient World

Pyramids of Giza

Hanging Gardens

Maussoleum

Statue of Zeus

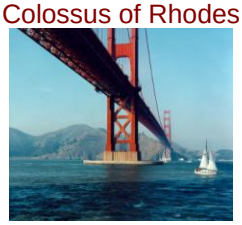

Temple of Artemis

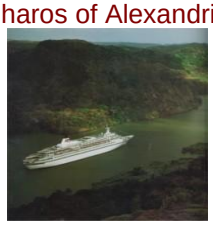
Colossus of Rhodes

Pharos of Alexandria

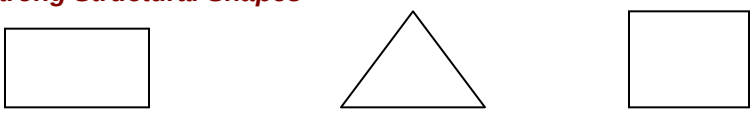
Additional Wonders of the Modern World

Chunnel Tunnel


Golden Gate Bridge


Panama Canal

Strong Structural Shapes

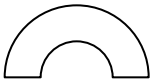


Rectangle Triangle Square

The ***triangle*** is a very strong and rigid shape that will not bend easily. A triangular prism is much stronger than a rectangular prism, a pentagonal prism, or any other multi-sided three-dimensional shape.

Structural Components

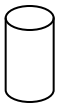
Arches — An arch is a common shape found in structures such as bridges. The arch can support a large load because the force of the load is carried down the arch to the foundation – spreading out the load.



Beams — A simple beam is a flat structure that is supported on both ends . There are different types of beams, including : ibeams, ubeams, tbeams and girders, or box beams

Truss — A truss is a framework of beams joined together, usually in the form of interlocking triangles. A cantilever is a beam that is supported only at one end. When weight is placed on the beam, the beam bends in an N-shape to resist the load.

Columns — A column is a solid structure that can stand by itself and is used to support beams.



Structural Stress, Fatigue, or Failure

Forces acting on structures can cause them to fail to perform their function.
Failure can occur if the force is too strong for the structure's design or if the force is acting on a vulnerable part of the structure (that part of the structure that will likely fail the most often).

A structure needs *strength* and *stiffness* to avoid failure.

- Shear - minor weaknesses in a material can cause failure because the particles move farther apart and are less attracted to each other. This can be caused by compression.
- Bend or Buckle - compression can also cause a material to bend and buckle - like a pop can that is stepped on. To prevent this reinforcements - stringers and ribs - are used to strengthen the structure
- Torsion - Twisting can cause material failure. When sections of the structure slide past each other the structure can crack or break in two. When the twisting action makes the structure unusable (even though it is not broken) it has failed because it has lost its shape.

Knowing that materials fail when external forces are applied can be useful information.

Buckle - Car bumpers are designed to buckle in a collision - as the metal fails, it absorbs some of the energy of the impact, which protects the occupants of the vehicle. Blades of grass on a sports field buckle as players land, which absorbs some of the impact forces on the players body.

(Crash Test Dummies)

Shear - Shear pins are used in outboard motors to prevent failure of the motor (when the propeller gets tangled in weeds, a shear pin breaks and the propeller becomes disengaged with the motor and gears. The clutch and automatic transmission in a vehicle take into account shear forces, which enable parts to slip past each other and produce a smooth ride.

Twist - Spinning wheels twist cotton or wool fibres so they lock together - making them strong enough to make cloth. Controlled twisting can also be useful in hair braids, ropes and telecommunication cables.

Metal Fatigue (Definition - The phenomenon leading to fracture under repeated or fluctuating stress.

Fatigue fractures start out at the beginning as minute cracks and grow under the action of fluctuating stress.)

Metal breaks down over time and extended use. (They get bent and twisted over and over). The particles in the metal move further apart and have less attraction to each other. When a crack develops it weakens the metal - metal fatigue - and can eventually fail even when a small force is applied.

Building for Structural Stability

Building a stable structure that will perform its function in the environment in which it will be is a challenge to designers. A careful analysis of all the forces that will be acting on the structure must be made. Engineers use their knowledge of forces to create designs that will most likely prevent the structures from failing.

Three key methods to help structures withstand forces are:

- **distribute the load** (in this way no one part of the structure carries most of the load)
- **direct the forces along angled components** (so that forces hold pieces together instead of pulling them apart)
- **shape the parts to withstand the specific type of force acting on them**

All materials have their limitations. Materials can be strengthened or weakened as they are made. (Concrete - if the correct recipe is followed, the concrete can be very strong (compressive strength), but if the proportions are incorrect, the resulting concrete can crumble and fail, however it does not have very good shear or torsion strength. Shear forces can be fatal in metal if the shear strength is not analyzed when the metal is manufactured. The cooling process can eliminate almost all defects if it is done properly. 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 between each brick. 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. Squeaks in floors are caused by fasteners that have loosened. 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).