how it might work….
engineering with 3 equations

and the internet….

Simon Smith

smithandwallwork engineers

the 3 equations…..

$\sum F_v = 0$

…..for objects not to move then equilibrium has to exist in translational and rotational directions…..

1. forces acting up and down must balance
2. forces acting left and right must balance
3. turning forces acting clockwise and anticlockwise must balance

$\sum F_H = 0$

$\sum Mp = 0$

who said that…..

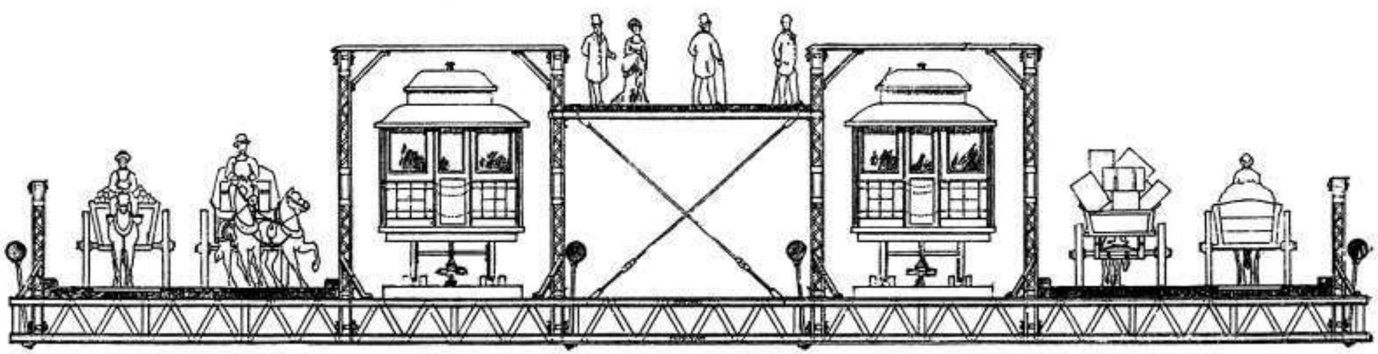
- **First Law**
  A body will remain at rest, or in a uniform state of motion unless acted upon by a force
- **Second Law**
  A force acting on a body will cause it to move (more strictly speaking accelerate).

  Force is related to acceleration by the equation, force=mass x acceleration ($F = ma$)
- **Third Law**
  Every action has an equal and opposite reaction

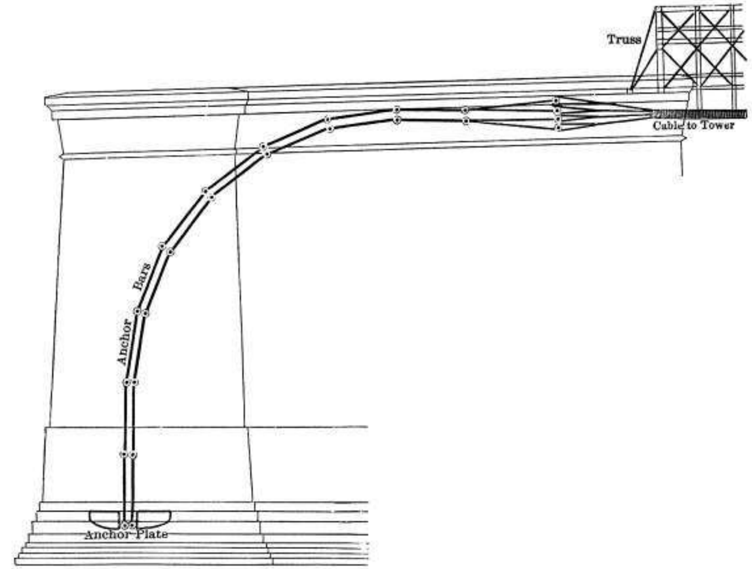
Isaac Newton
17th century

Brooklyn Bridge NY – 1883

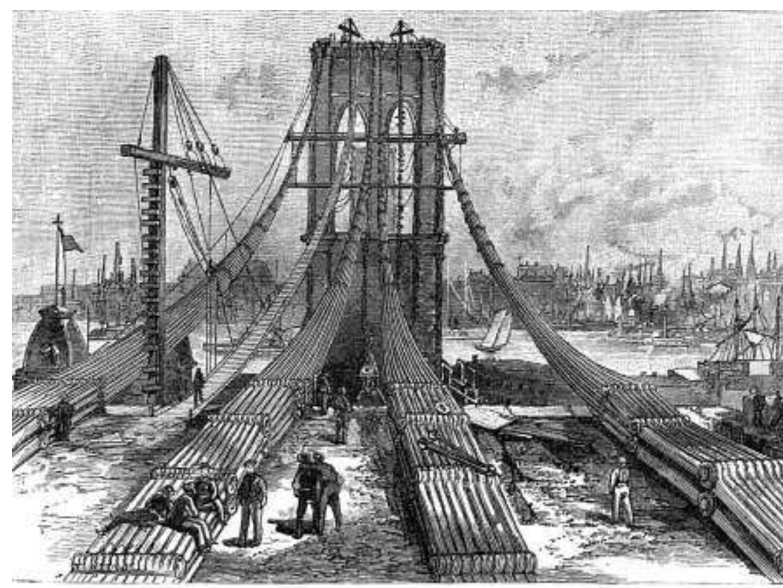
….cable design….



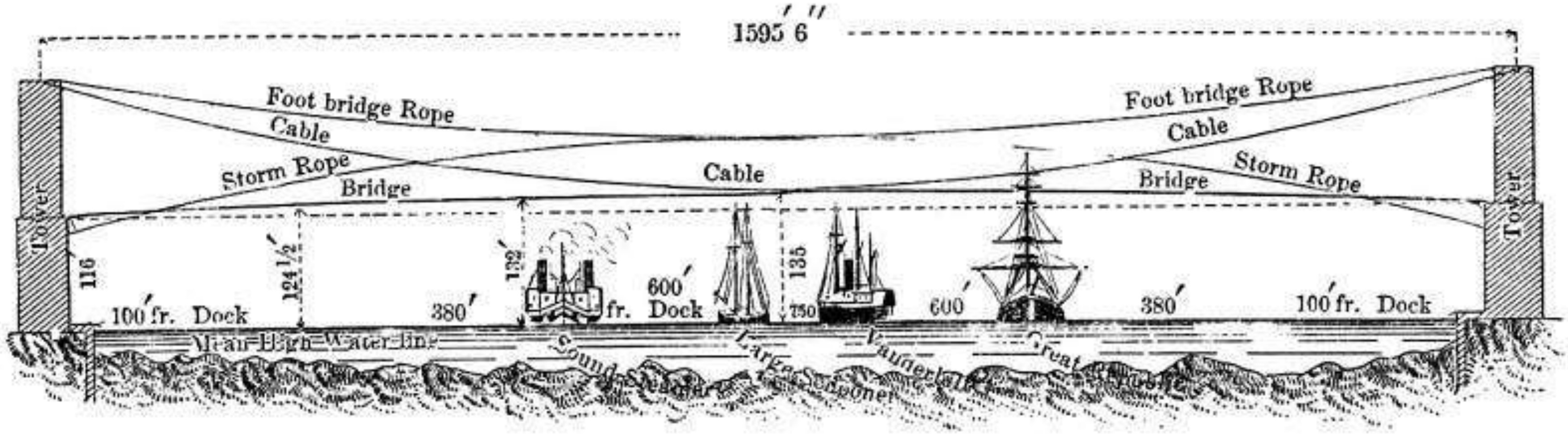
SECTION OF BRIDGE, SHOWING FOOT, RAIL, AND CARRIAGE WAYS.



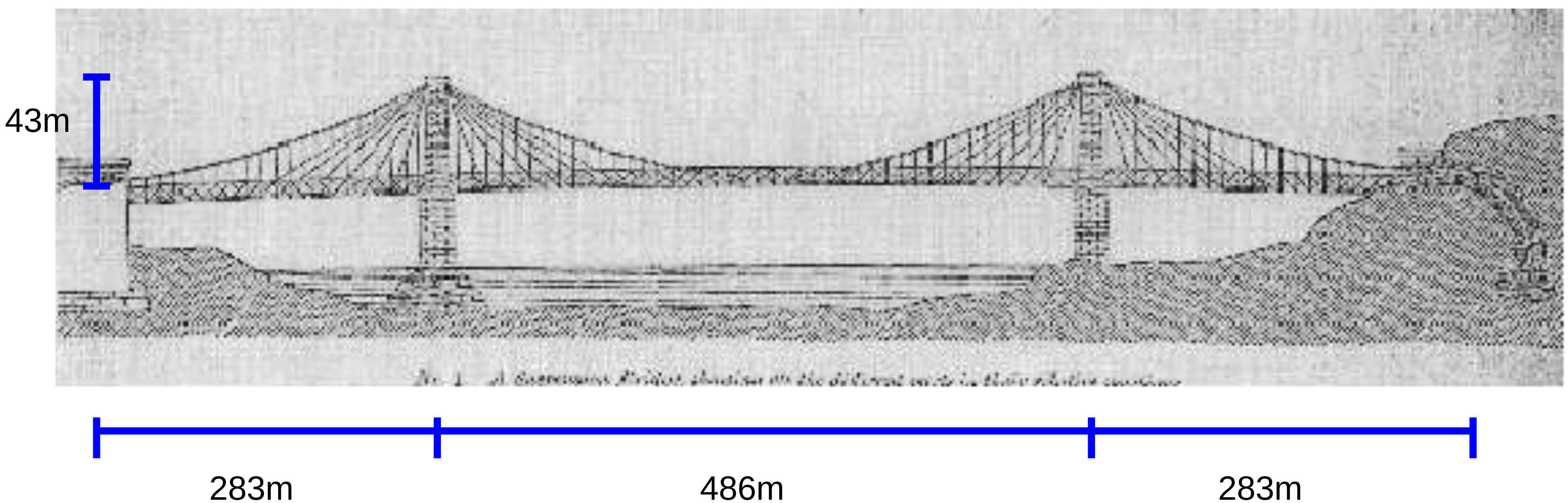
SECTION OF TOP AND BACK OF ANCHORAGE—SIDE VIEW.



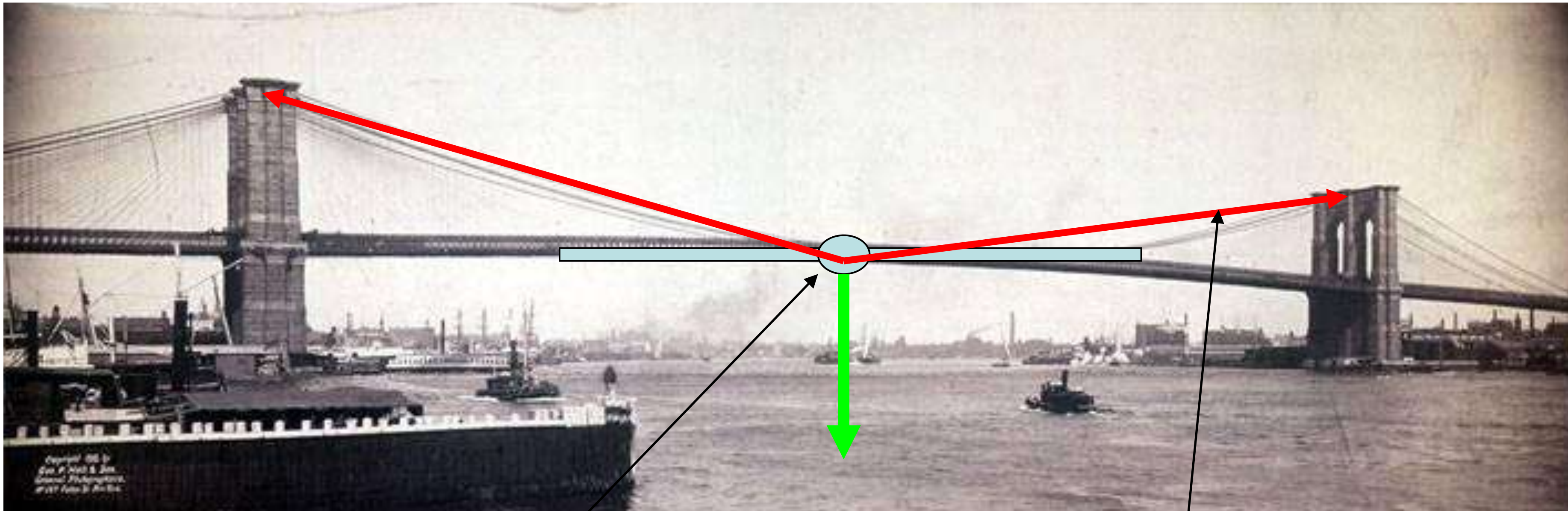
THE BROOKLYN ANCHORAGE.



ELEVATION OF BRIDGE, SHOWING TEMPORARY ROPES USED IN CABLE-MAKING.



structural model

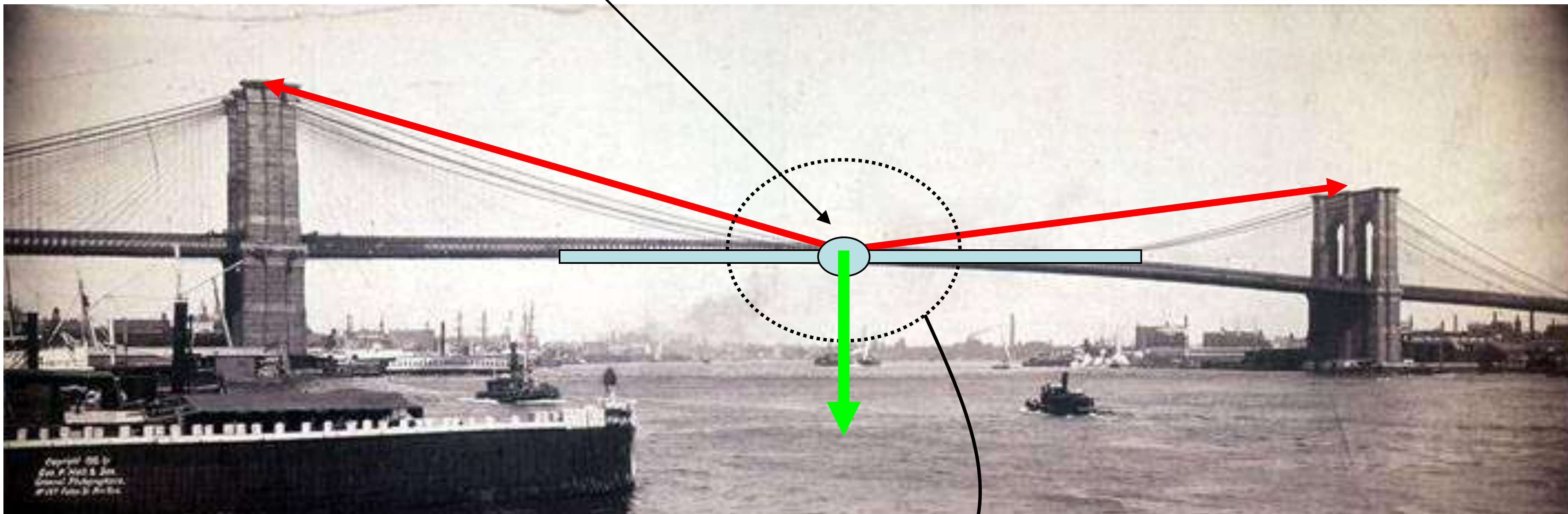


load from bridge deck concentrated at centre of span, point load representing half the span of the bridge

suspension cables represented by simplified straight ‘wires’ to centre of span

Deck area 243m x 24m (5800m^2)

Represents load of 4000t based on 700kg/m^2

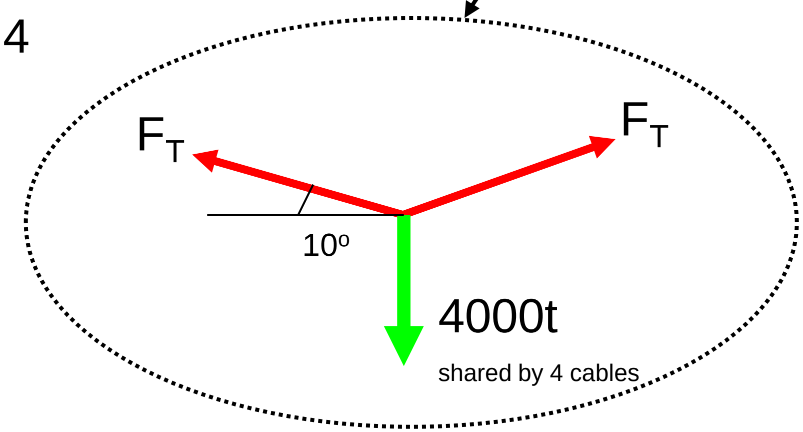


Using vertical equilibrium tension force in cable is given by:

$2 \times F_T \times \sin 10^o = 4000t / 4$

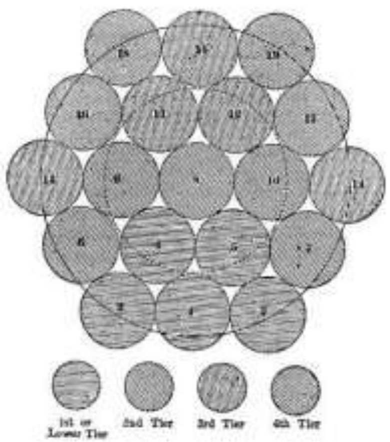
therefore $F_T = 2880t$

$$\sum F_v = 0$$

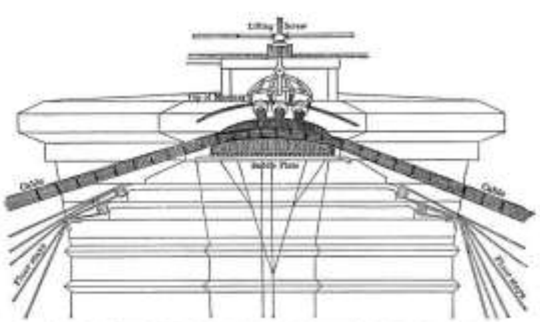


http://www.inventionfactory.com/history/RHAbridg/bb.html

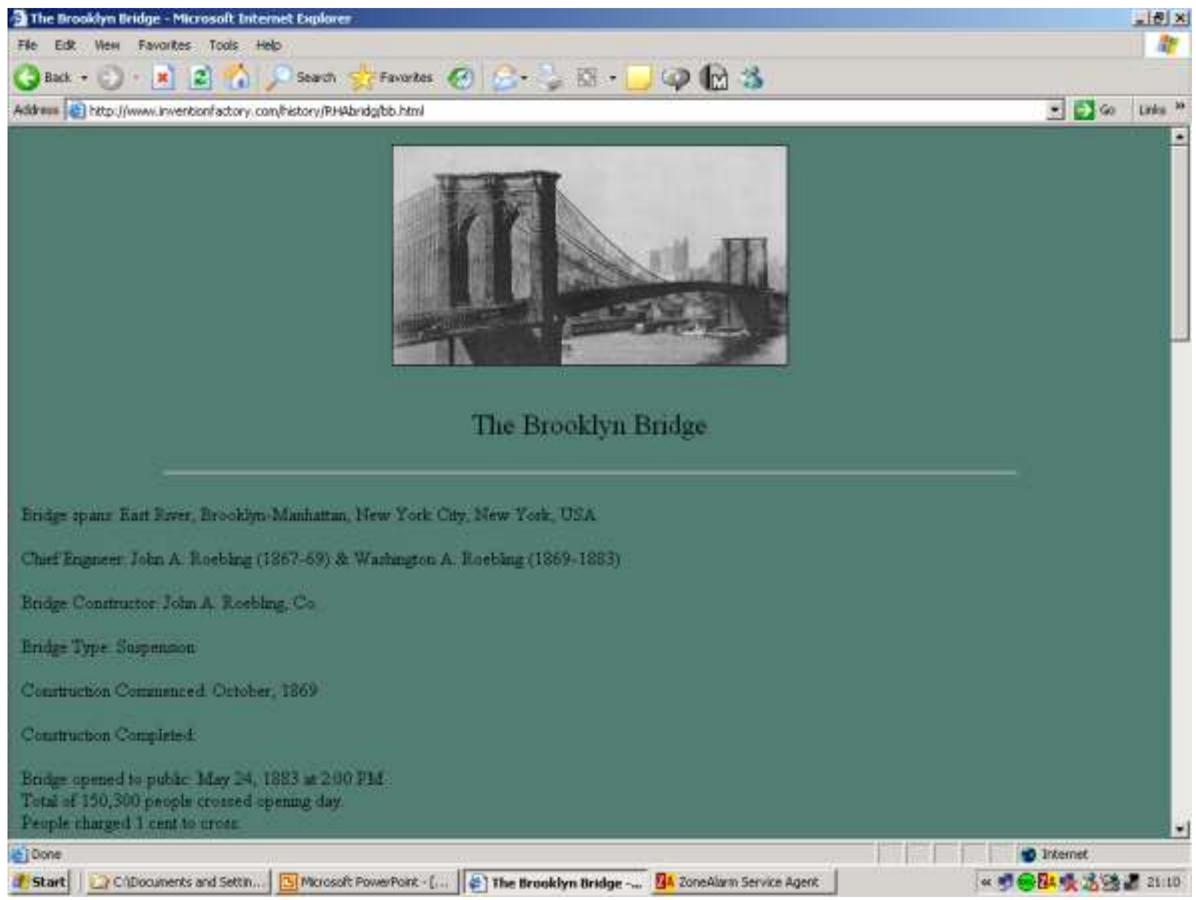
'….Number of supporting cables: 4
Diameter of each cable: 15 ½ inches
Length of each single wire in cables:
Diameter of each single wire in cables:
A cable contains 19 strands, containing 2381 wires at a total of 21,432 wires in each cable..??
Ultimate strength of a cable: 11,200 tons……'



SECTION OF CABLE, SHOWING STRANDS.



SECTION OF TOWER, SHOWING SADDLE-PLATE AND LOWERING OF STRAND INTO POSITION.



http://www.endex.com/gf/buildings/bbridge/bbridgefacts.htm

'…....Inventor and manufacturer of steel wire cable - John A. Roebling
Tested cable wire strength - 160 ksi
Maximum load on single cable (Live and Dead Load) - 6,000 kips
Ultimate strength of cables - 24,600 kips
Cable factor of safety - 24,600/6,000 = 4.1
Maximum cable sag - 130 feet……..'

http://www.unc.edu/~rowlett/units/dictK.html

'….kip [1]

an informal unit of force, sometimes used by engineers to express the amount of weight borne by a structure.
One kip equals 1000 pounds (453.59 kilograms) of force or about 4.4482 kilonewtons.
The name of the unit is an abbreviation of "kilopound."……'

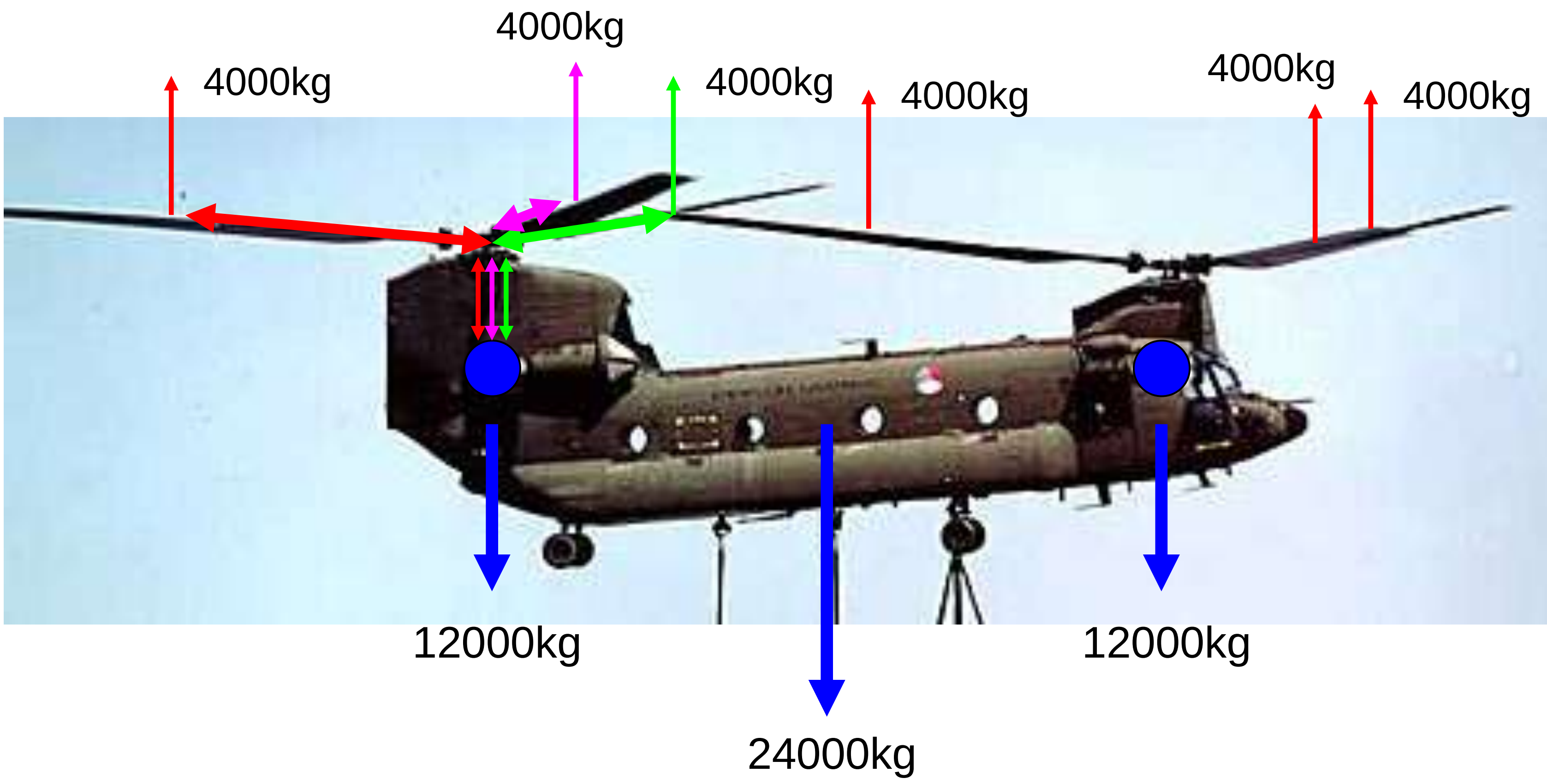
6000 kips = 2722 t

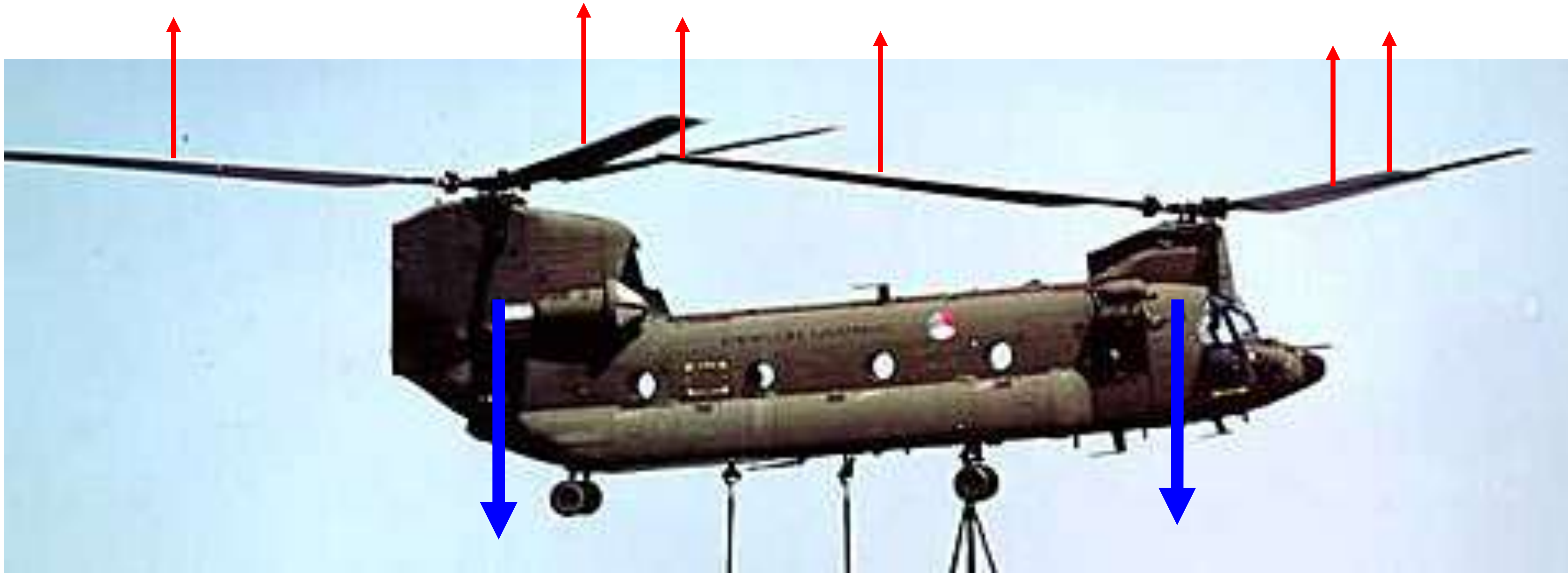
…we calculated 2880 t…

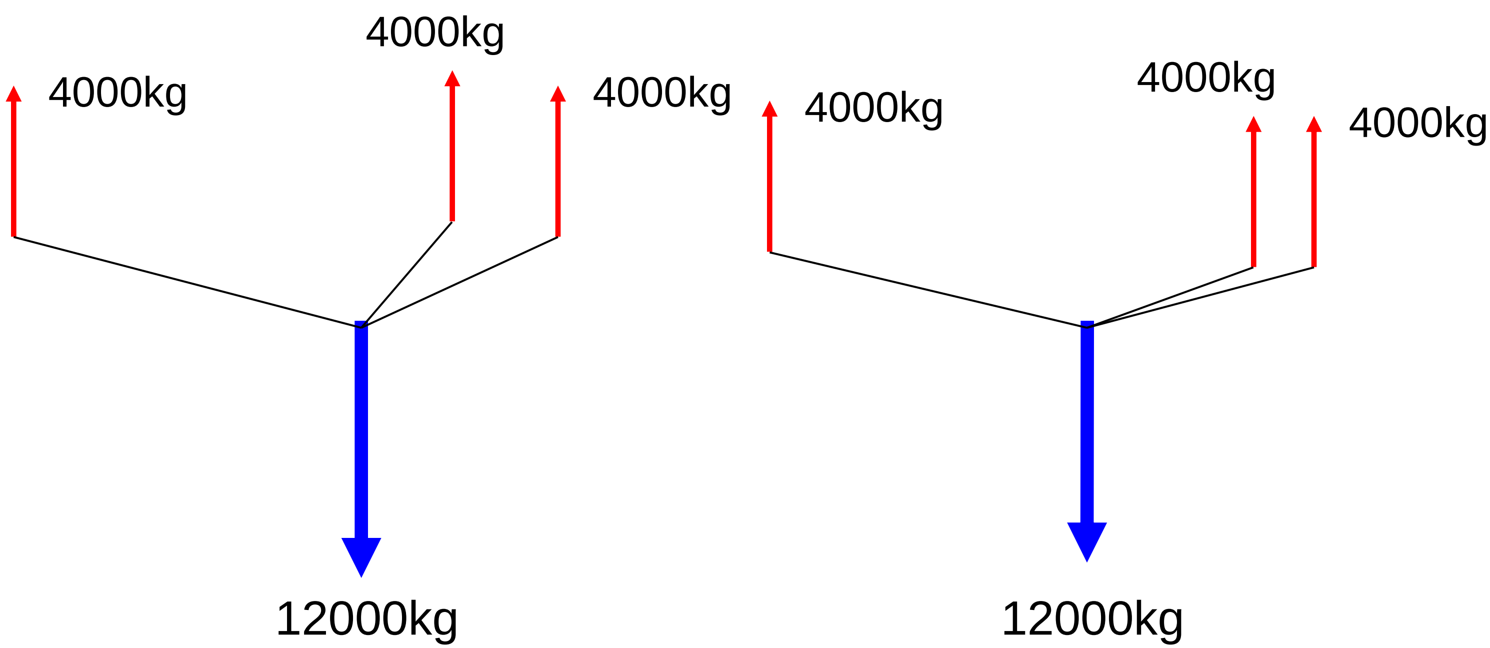
chinook helicopter

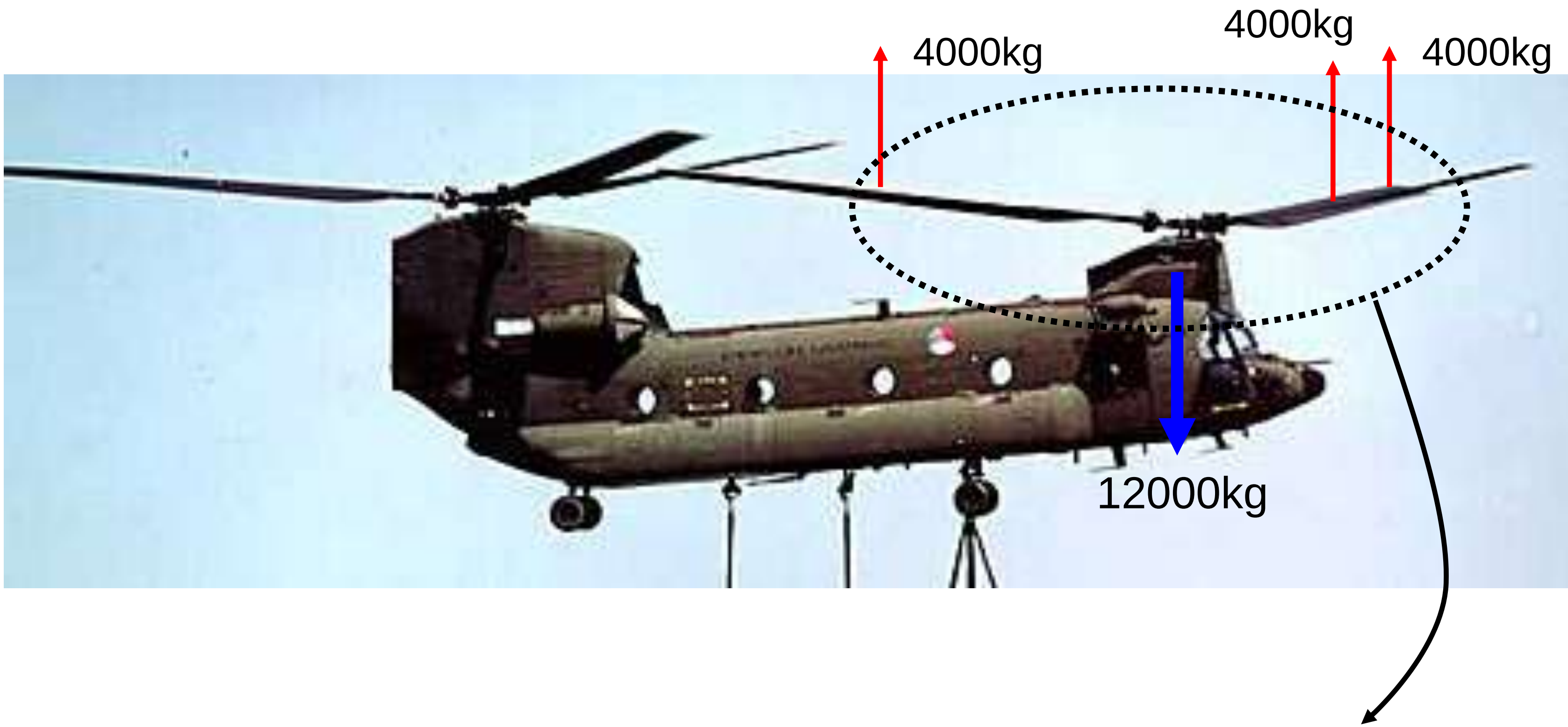
…rotor blade design…

structural model





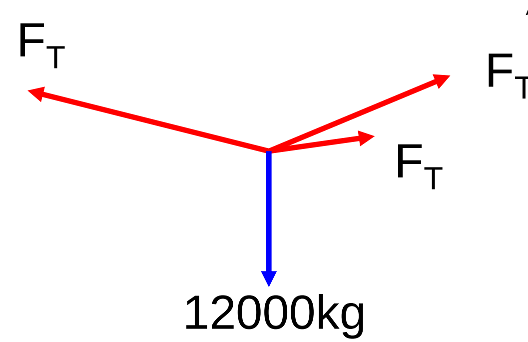

4000kg
4000kg
4000kg
4000kg
4000kg
4000kg
12000kg
12000kg



use vertical equilibrium to find the tensile force in each rotor blade:

$3 \times F_T \times \sin 6^o = 12000$ kg

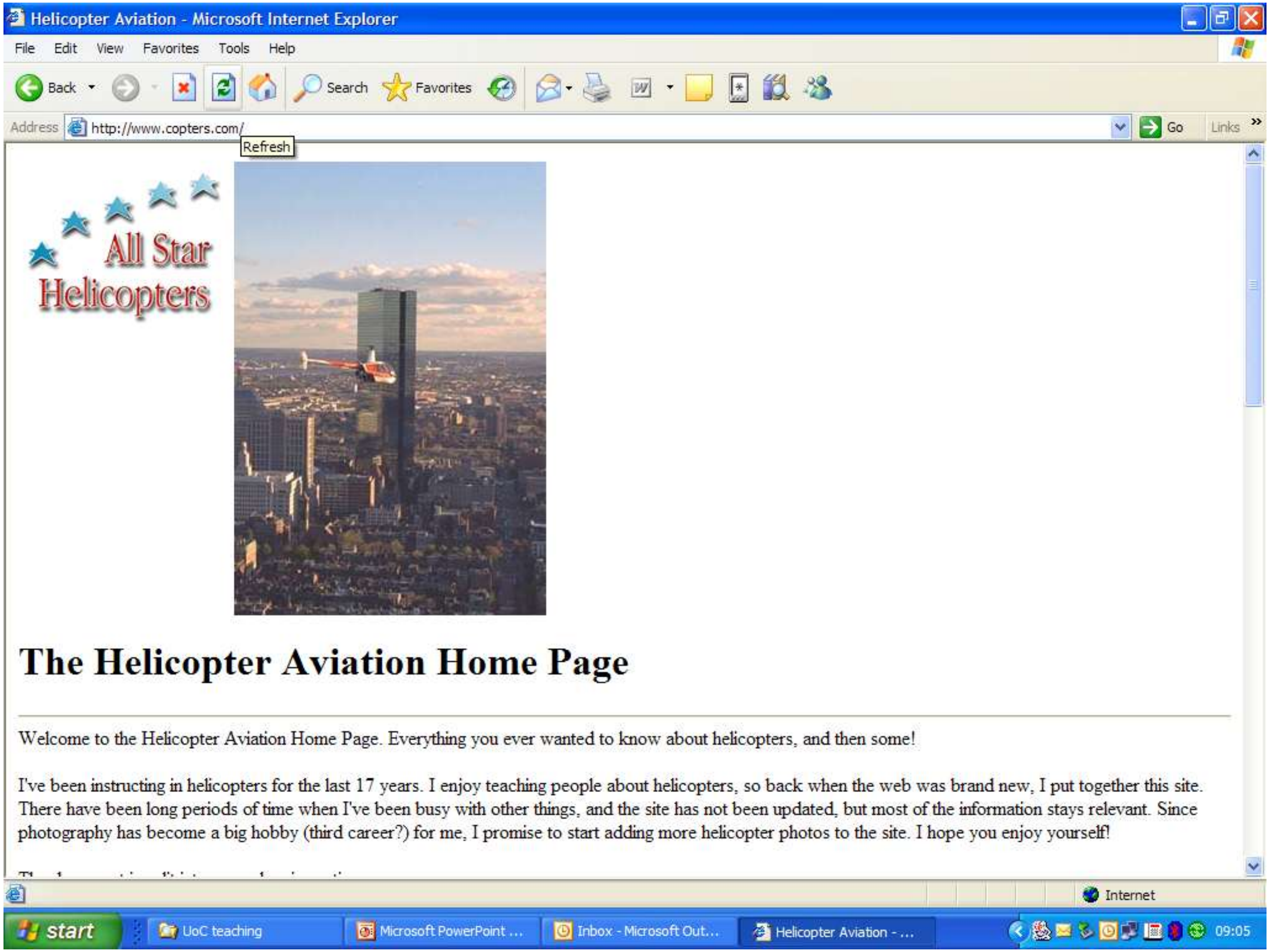
therefore $F_T = 38267$ kg



$$\sum F_v = 0$$

www.copters.com/aero/centrifugal_force.html

'…larger helicopters may develop up to 40 tons of centrifugal load on each blade …'



http://www.lawton-constitution.com/cball/pages/can102005.pdf

'….Spc. Shawn Hernandez, 7th Battalion, 158th Aviation Regiment, leads a line of eight Soldiers carrying and fully supporting a 356-pound CH-47 Chinook rotor blade…..'

Spc. Shawn Hernandez, 7th Battalion, 158th Aviation Regiment, leads a line of eight Soldiers carrying and fully supporting a 356-pound CH-47 Chinook rotor blade. Each Chinook has six blades, which were removed and packed inside the helicopter from which they were plucked. Then the [illegible] helicopters were loaded, two-by-two, onto several Air Force cargo transport aircraft.

what is the RPM required to achieve 38627kg centrifugal force in rotor blade?

F (N) = mass (kg) x angular velocity^2 (rads^{-1}) x radius (m)

386KN = 356lb x angular velocity^2 x 4.57m

$$v = \sqrt{\frac{386000N}{161.5kg \times 4.57m}}$$

= 22.87rad/s

With a rotor diameter of 18.3m and blade centre of mass at half this…..

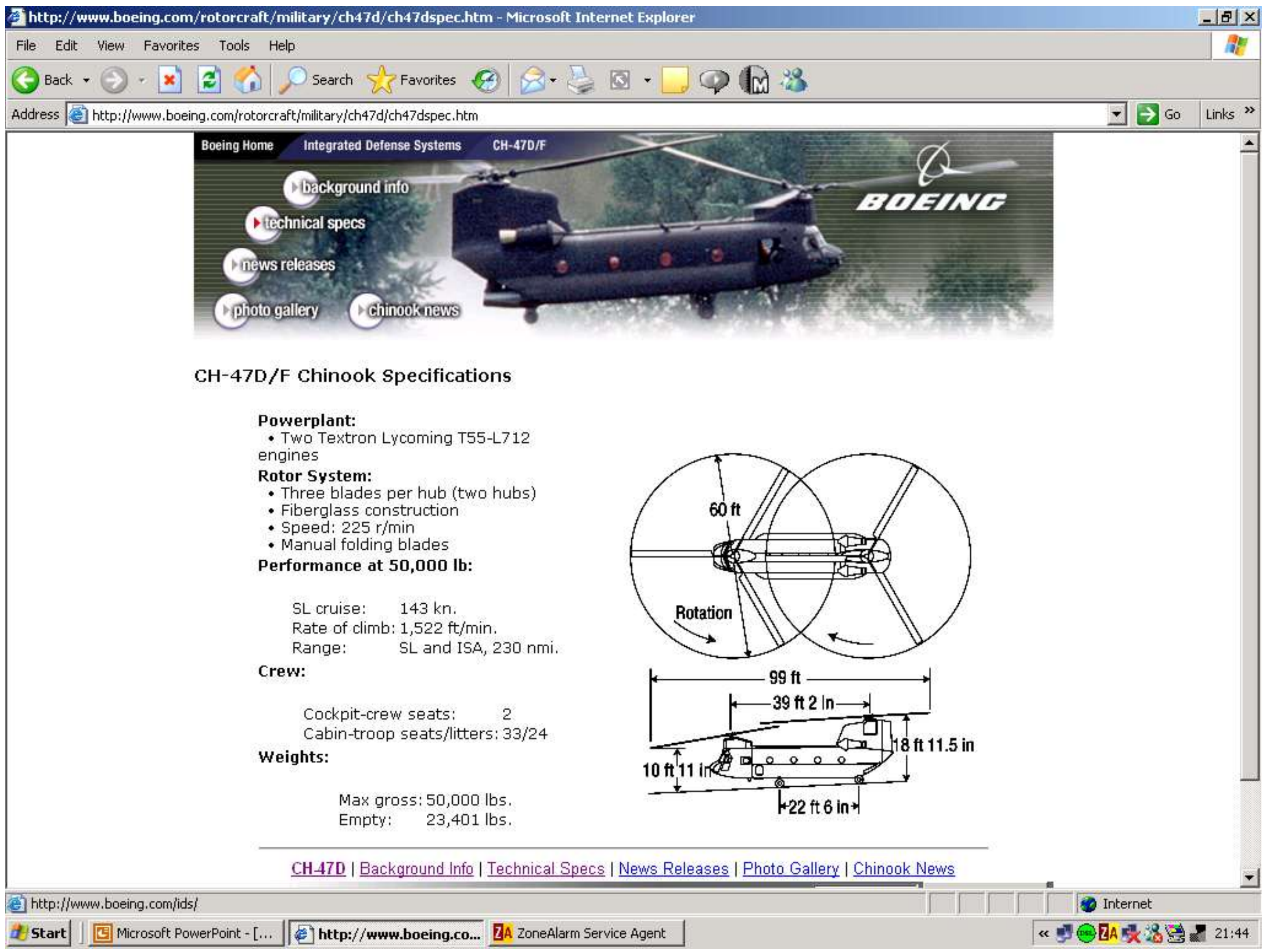
22.87rad/s = 218 rpm

http://www.boeing.com/rotorcraft/military/ch47d/ch47dspec.htm

'……Rotor System:

- Three blades per hub (two hubs)
- Fibreglass construction
- Speed: 225 r/min
- Manual ….'

..we calculated an rpm of 218….

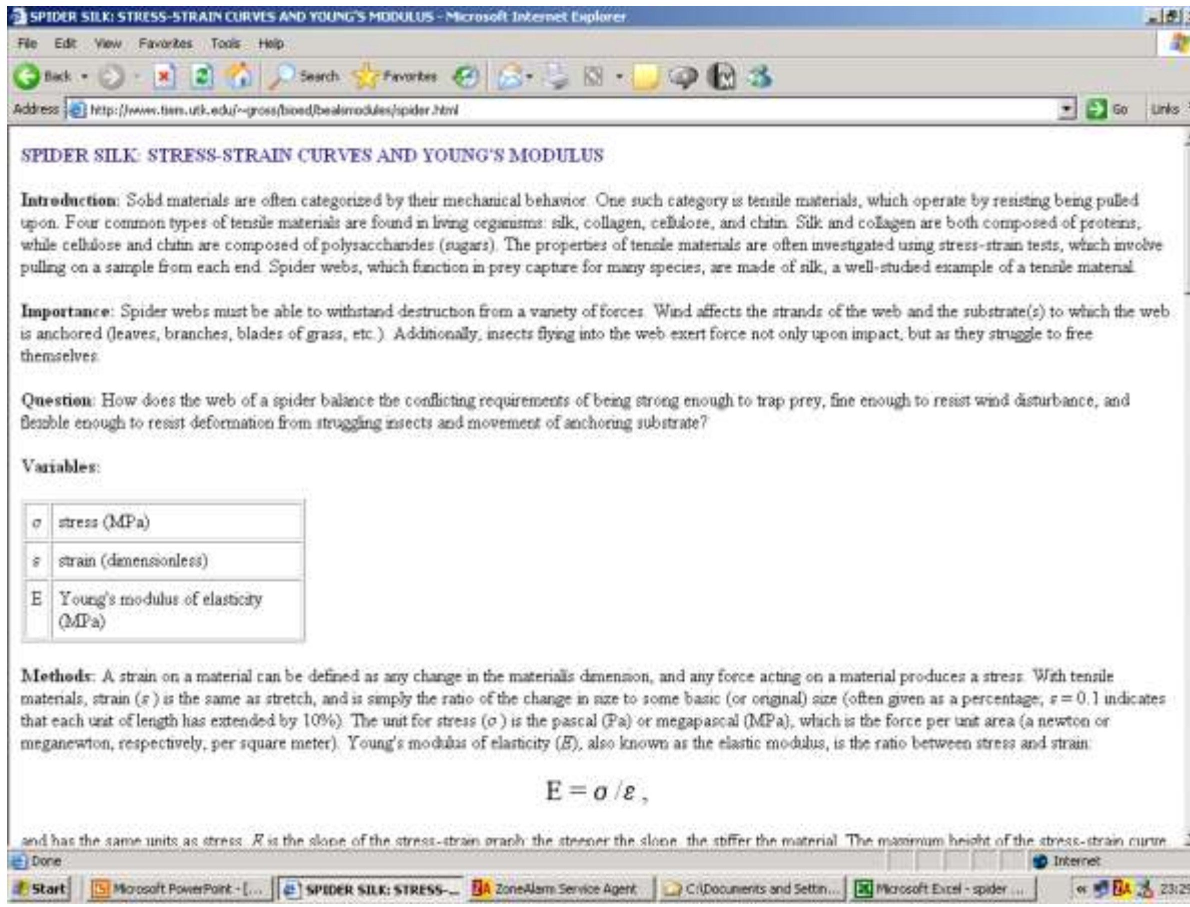


spider webs

…silk thread design…

http://www.tiem.utk.edu/~gross/bioed/bealsmodules/spider.html

'….from the stress-strain graph we can see that the spiral's mean extensibility, which is the maximum strain (or stretch) before breaking, was 476%, as compared to the radii's mean extensibility of 39.4% The tensile strength of the capture spiral is 1338 MPa, while the tensile strength of the radial thread is 1154 MPa. For comparison, the tensile strength of "mild" steel is 400 MPa….'



SPIDER SILK: STRESS-STRAIN CURVES AND YOUNG'S MODULUS

Introduction: Solid materials are often categorized by their mechanical behavior. One such category is tensile materials, which operate by resisting being pulled upon. Four common types of tensile materials are found in living organisms: silk, collagen, cellulose, and chitin. Silk and collagen are both composed of proteins, while cellulose and chitin are composed of polysaccharides (sugars). The properties of tensile materials are often investigated using stress-strain tests, which involve pulling on a sample from each end. Spider webs, which function in prey capture for many species, are made of silk, a well-studied example of a tensile material.

Importance: Spider webs must be able to withstand destruction from a variety of forces. Wind affects the strands of the web and the substrate(s) to which the web is anchored (leaves, branches, blades of grass, etc.). Additionally, insects flying into the web exert force not only upon impact, but as they struggle to free themselves.

Question: How does the web of a spider balance the conflicting requirements of being strong enough to trap prey, fine enough to resist wind disturbance, and flexible enough to resist deformation from struggling insects and movement of anchoring substrate?

Variables:

σ	stress (MPa)
ε	strain (dimensionless)
E	Young's modulus of elasticity (MPa)

Methods: A strain on a material can be defined as any change in the materials dimension, and any force acting on a material produces a stress. With tensile materials, strain (ε) is the same as stretch, and is simply the ratio of the change in size to some basic (or original) size (often given as a percentage; $\varepsilon = 0.1$ indicates that each unit of length has extended by 10%). The unit for stress (σ) is the pascal (Pa) or megapascal (MPa), which is the force per unit area (a newton or meganewton, respectively, per square meter). Young's modulus of elasticity (E), also known as the elastic modulus, is the ratio between stress and strain:

$$E = \sigma / \varepsilon ,$$

and has the same units as stress. E is the slope of the stress-strain graph: the steeper the slope, the stiffer the material. The maximum height of the stress-strain curve

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

'…**Spider silk** is a fibre secreted by spiders. Spider silk is a remarkably strong material. Its tensile strength is comparable to that of high-grade steel -- according to *Nature* (see reference below), spider silk has a tensile strength of roughly 1.3 GPa, while one source [1] lists a tensile strength for one form of steel at 1.65 GPa. However, spider silk is much less dense than steel; its ratio of tensile strength to density is perhaps 5 times better than steel—as strong as aromatic nylon filaments, such as DuPont's Kevlar….'

bee mass 0.1 gram

bee speed 10m/s

The bee is stopped when it's kinetic energy is absorbed by the spider web deflecting…..

ie: ½ x mass x velocity^2 = force x distance

$$\frac{1}{2} m v^2 = F d$$

spider silk strength 1150N/mm^2

spider silk diameter 0.015mm

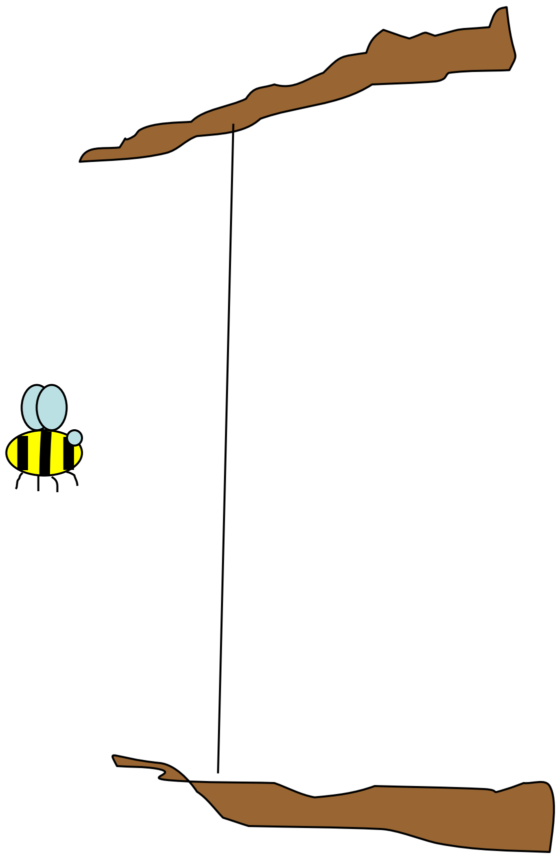
web diameter say 15cm

structural model

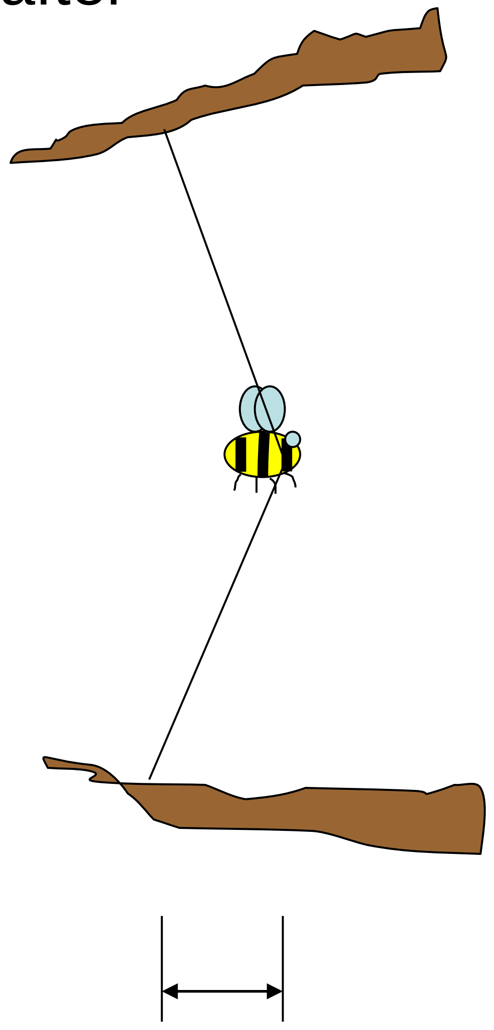
radial webs act in tension
under fly impact load

structural model

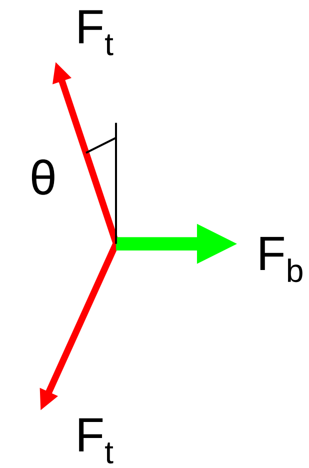
before



after



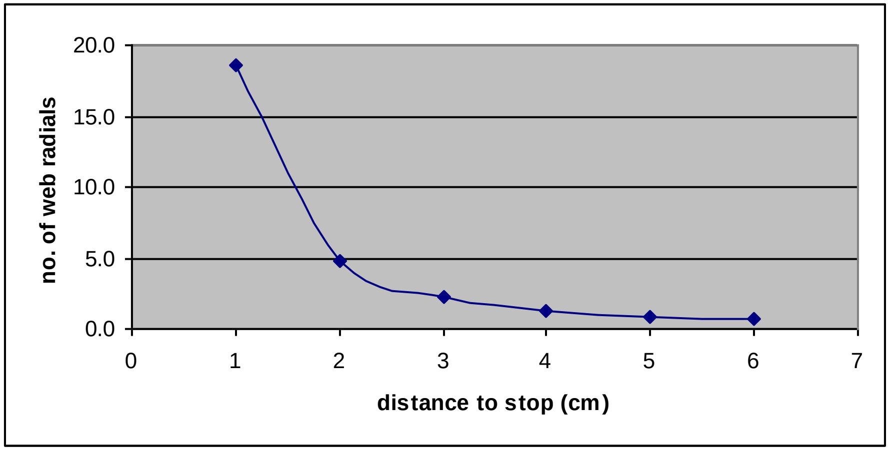
model

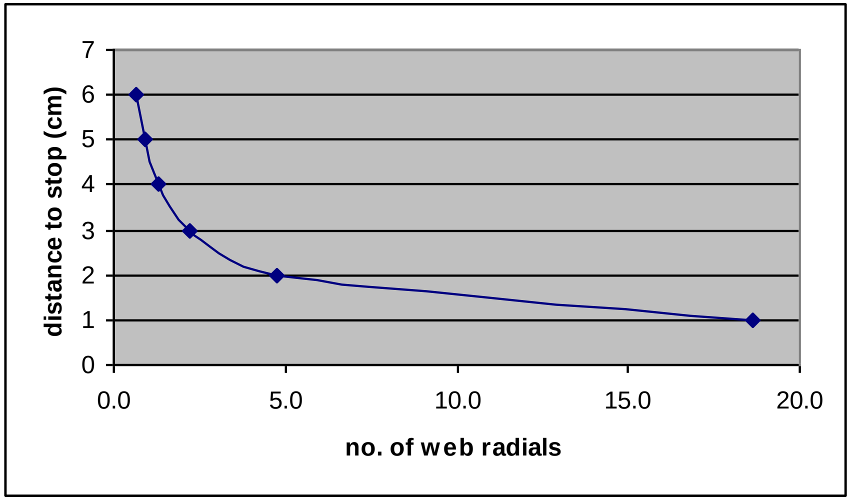


$$\sum F_H = 0$$

$$F_b = 2 \times \sin\theta \times F_t$$

speed (m/s)	10	10	10	10	10	10
distance to stop (cm)	1	2	3	4	5	6
kenetic energy (J)	0.005	0.005	0.005	0.005	0.005	0.005
stopping force (N)	0.500	0.250	0.167	0.125	0.100	0.083
spider web diameter (cm)	15	15	15	15	15	15
web silk strength (N/mm^2)	1150	1150	1150	1150	1150	1150
web silk diameter (mm)	0.015	0.015	0.015	0.015	0.015	0.015
web angle (deg)	7.59	14.93	21.80	28.07	33.69	38.66
web silk elongation (%)	0.9%	3.5%	7.7%	13.3%	20.2%	28.1%
silk breaking force (N)	0.20	0.20	0.20	0.20	0.20	0.20
no. web radials req'd	18.6	4.8	2.2	1.3	0.9	0.7





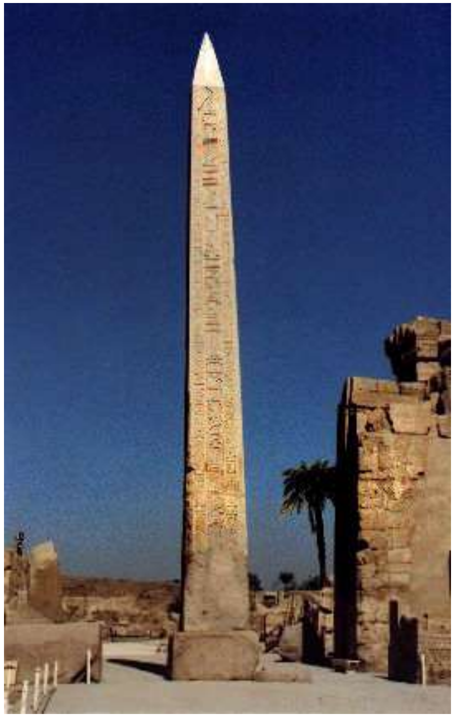
cleopatra’s needle

…stopping it falling over…

http://members.aol.com/Sokamoto31/obelisk.htm#alllist

Paris

Cairo



Luxor

Rome

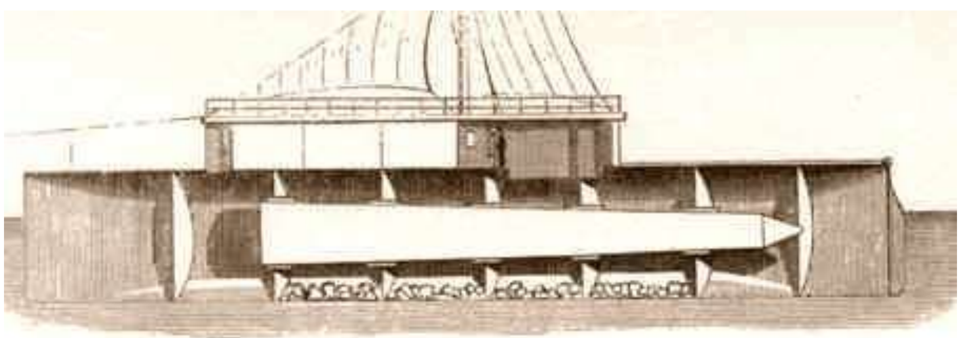
http://www.historic-uk.com/HistoryUK/England-History/CleopatrasNeedle.htm

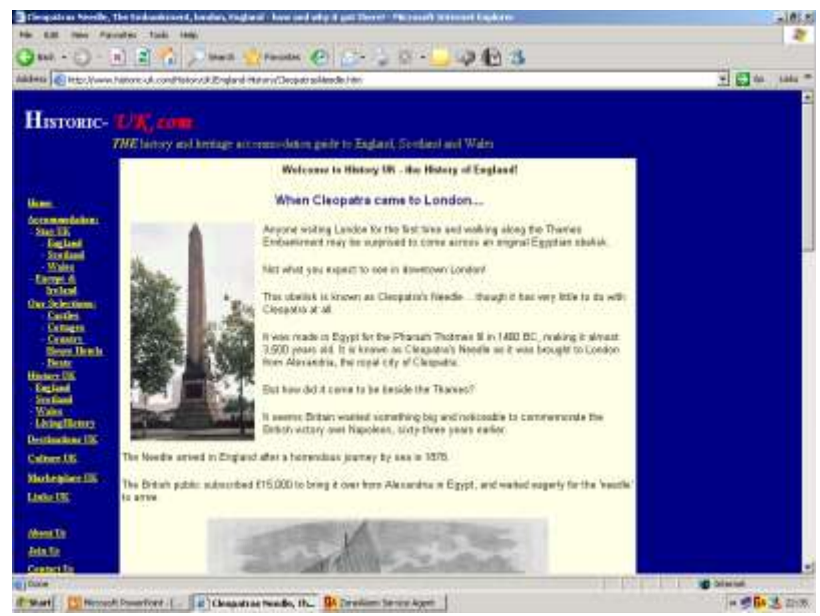
'....a specially designed cigar-shaped container ship (called the Cleopatra) was used to convey the needle to London, towed by a steam ship called the Olga.

…during the sea journey, stormy seas were encountered and 6 men lost there lives when the Olga had to cut the Cleopatra free.

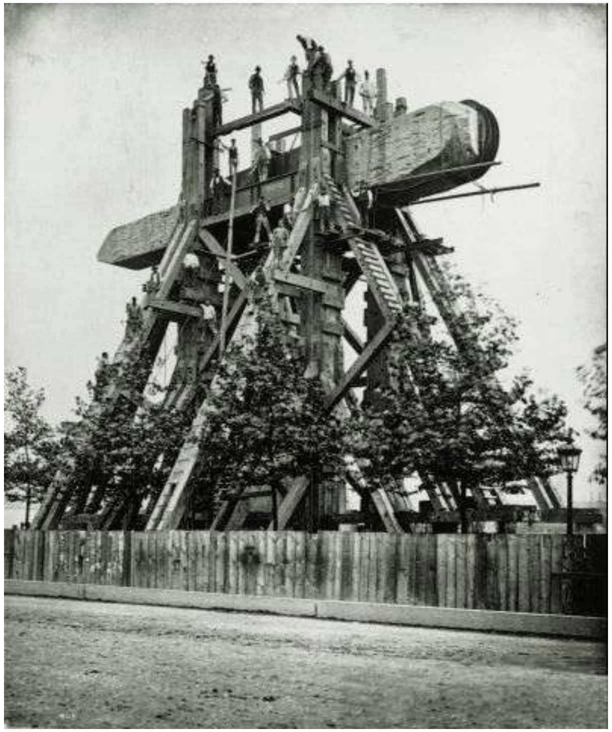
……five days later a ship spotted the Cleopatra floating peacefully and undamaged off the northern coast of Spain, and towed her to the nearest port, Ferrol.

….following her narrow escape, another steam-ship, the Anglia, was sent to tow the Cleopatra home. The 'needle' was winched into position on the Embankment in September 1878…..'





http://members.tripod.com/obeliscos_egipcios/images_en.htm



http://www.victorianlondon.org/buildings/cleopatrasneedle.htm

'….as the weight of the obelisk is only 150 tons…..
…the obelisk is 66 feet long over all, and the base (8 feet 6 inches square)….'

Victorian London - Buildings, Monuments and Museums - Cleopatra's Needle

This obelisk of ancient Egypt, which has been left lying so long half buried in the sand at Alexandria, is now about to be made an ornament to the city of London. Its removal has been considered a matter of such great expense that the British Government has not felt justified in undertaking it and, had it not been for the private generosity of Dr. Erasmus Wilson, and the ingenuity of the engineer, it would most likely have remained to form the foundations of the new houses leading to the Alexandria Railway Station....

The consulting engineer is Mr. B. Baker, well known by his connection with the Metropolitan Railway, and the work will be performed by Mr. Dixon. The removal of this obelisk will be accomplished in the following manner: A wrought-iron cylindrical pontoon, 92 feet long and 15 feet in diameter, tapered at each end to a vertical edge, will be its only support in the water. Its draught is 9 feet, and displacement 270 tons. If completely submerged, its power of floatation is equal to 705 tons, and as the weight of the obelisk is only 150 tons, with 30 tons ballast, it is evident that there is no chance of its foundering.

The pontoon is furnished with a series of bulkheads, or diaphragms, which support the obelisk at about every 10 feet, and suitable elastic packing secures it from shocks. The obelisk is 66 feet long over all, and the base (8 feet 6 inches square) will be placed forward, giving great buoyancy to the forepart, as the apex is close to the stern, which will be furnished with a rudder. On top of the pontoon and near its centre, will be placed a small deck house, with steering-wheel in the forepart and accommodation for three men. There is a long narrow hurricane-deck above the steering-room, and a short mast with two small sails surmounts the whole ... The boat will be towed by steamer to London, the sails being merely used for steadying purposes. It is calculated that the roll will not be excessive....

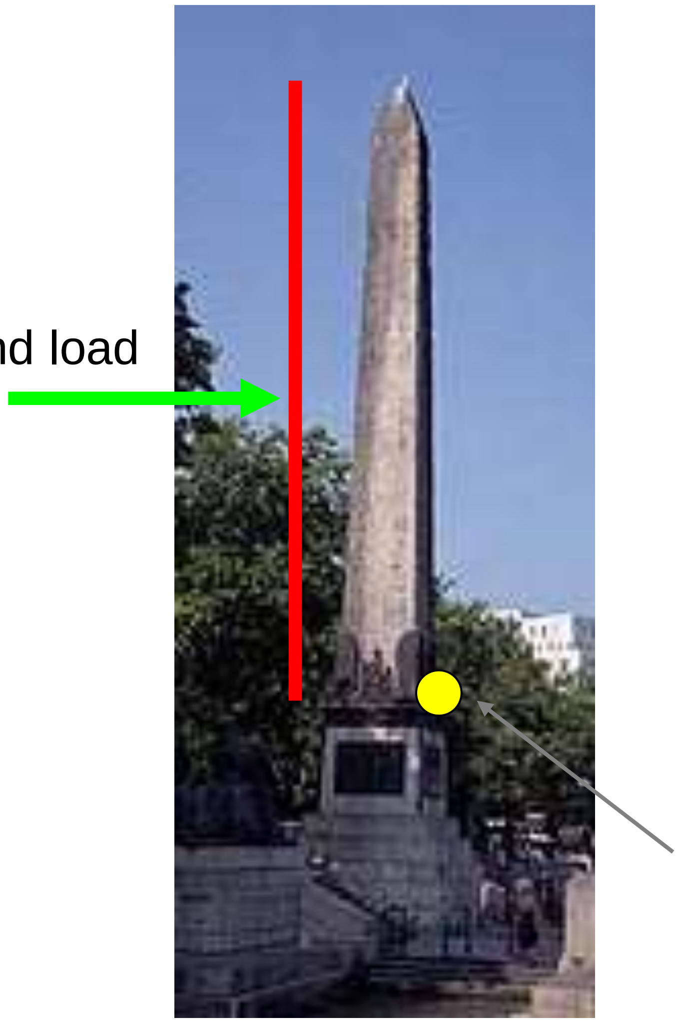
Illustrated London News, March 10th 1877

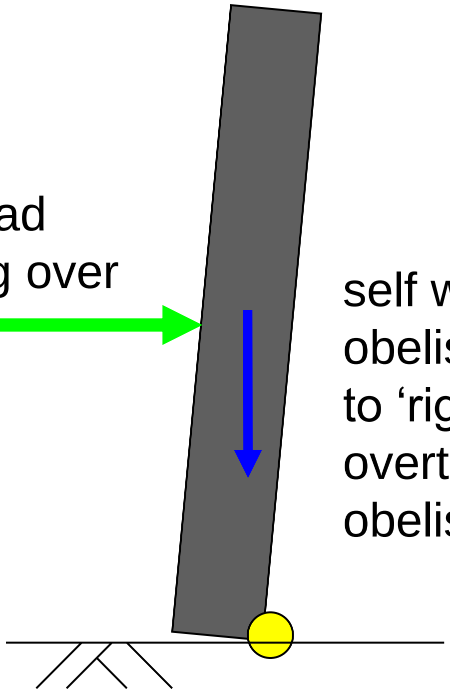
Cleopatra's Needle.— -Victoria Embankment, opposite the end of Salisbury-street, Strand, between Waterloo-bridge and Charing-cross. NEAREST Railway Station, Temple; Omnibus Routes, Waterloo-bridge and Blackfriars-bridge; Cab Rank, Embankment.

Charles Dickens (Jr.), Dickens's Dictionary of London, 1879 why would it fall over……..

what stops it from falling over……

do we have to ‘bolt’ down obelisk………

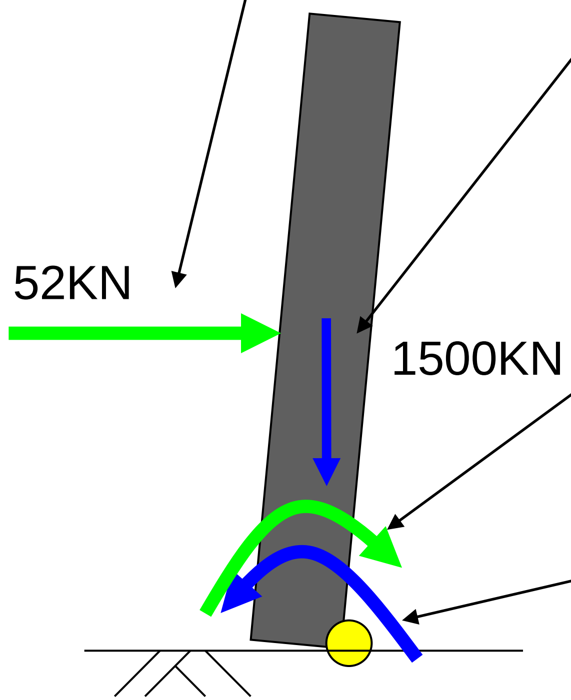




….wind load on obelisk:
frontal area = 20m x 2.6m = 52m^2
unit wind load = 1KN/m^2 (100kg/m^2)
total wind load = 52KN

….self weight of obelisk:
mass = 150t
weight = 1500KN

In order for the obelisk to remain stable the overturning force must be less or equal to the restoring force.



the overturning force measured about the point of rotation is:

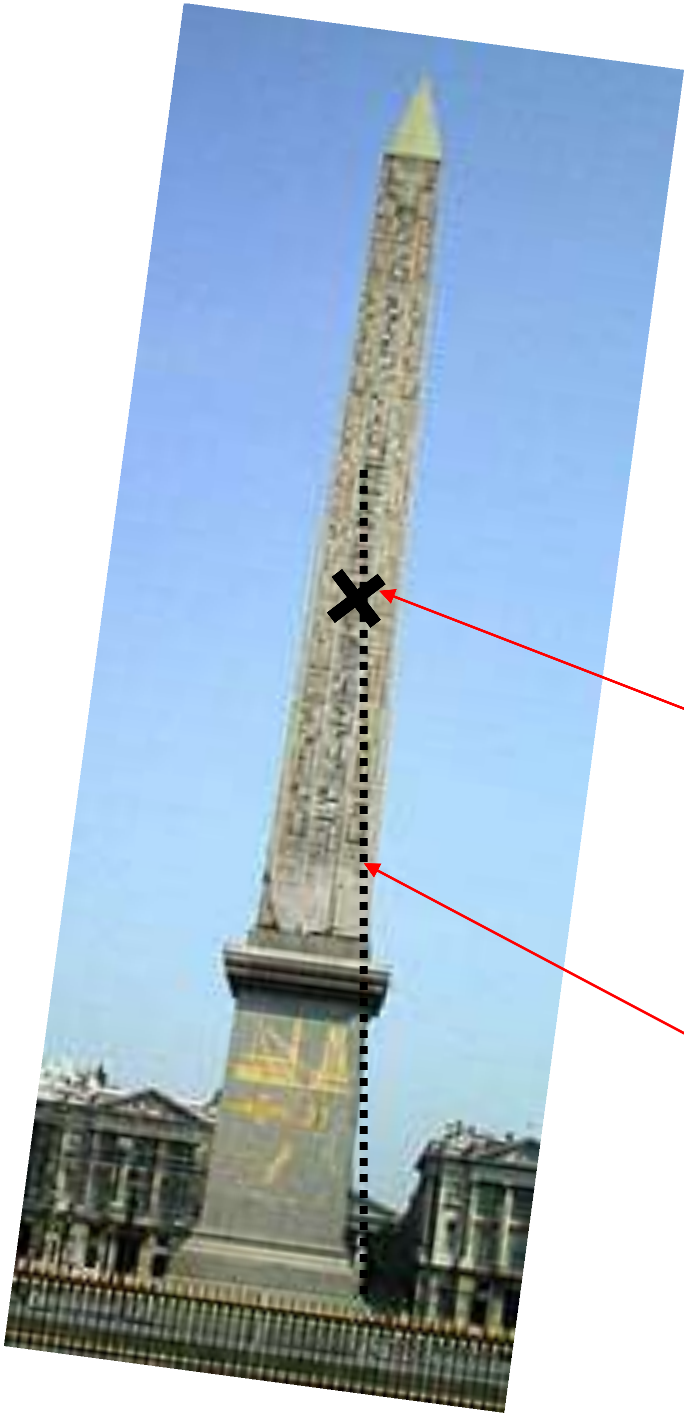
52KN x 10m = 520KNm

the restoring force measured about the point of rotation is:

1500KN x 1.3m = 1950KNm

….therefore factor of safety against overturning is nearly 4…..

how far over could you push an obelisk before it becomes unstable?



……..until the centre of gravity of the obelisk ‘wanders’ outside of the obelisk base footprint.

cross represents centre of gravity of obelisk

dotted line represents a ‘plumb’ line