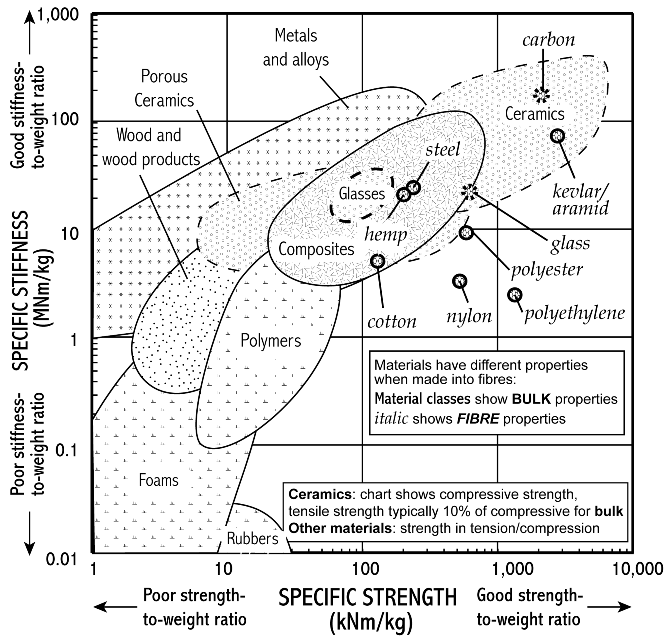
Ropes

Ropes and tethers are designed to support tensile loads; either stationary loads as for a suspension bridge, or dynamic loads as for a falling rock climber.

What is a rope?

A rope is a bundle of fibres/threads/wires twisted together. So why not just use a thicker single strand? While a single strand should have the same strength as a rope of the same cross sectional area there are several reasons why a rope is often a better solution.

- If one fibre fails the rope remains intact – whereas a rope made of a single large fibre would fail catastrophically.
- Thin fibres often have higher strength than thick ones made from the same material. Glass fibres are a good example of fibres which are strong in tension when thin because they are unlikely to contain a strength limiting defect. Drawn polymer fibres have much better mechanical properties than polymer products made by ordinary polymer processing, but such fibres can only be made in small diameters.
- A multi-stranded rope is more flexible than a single strand of the same diameter – for example multi-stranded copper 13A cable is much easier to bend than the single strand copper wire of the same diameter used in ring-main cables.



What are we looking for in a rope?

	Required strength	*Allowable weight*	*Stretch requirements*	*Flexibility*	*Impact toughness*	*Creep resistance*
Suspension cable	high	low	high Young' s modulus	little required	medium	high
Climbing rope	medium	low	high elongation	great	high	low

Suspension cables

Since these are used to suspend bridges the most important criterion is strength in tension. Because it is important that the bridge does not flex too greatly under strong winds or during the passing of large lorries, the stiffness (Young's modulus) must also be high. In addition, for very large span bridges the weight of the cables themselves is also important. For this reason a specific stiffness – specific strength chart (above) is useful for identifying suitable materials – the chart shows a selection of materials available as fibres. Until recently steel cables have been used for bridge type applications. **Steel wire** such as that used inside pianos (patented steel wire) can have a very high tensile strength, but it is quite heavy. Recently very high specific stiffness and strengths have been recorded for **synthetic fibres**. These are now used in suspension bridges by incorporating fibres into a matrix to form a composite bundle. This is then twisted with others to form a rope. Creep properties (the gradual extension over time under a tensile load) are also very important.

Climbing ropes

Unlike suspension cables, climbing ropes are not designed to be continuously under load. This means that creep is much less of an issue. Climbing ropes are primarily used in the event of a fall. If a climber should fall, then the rope must be able to stop the fall without breaking, but also without too rapid a deceleration (the opposite of acceleration) since this can also cause injury. This design constraint is met by requiring materials with a large *elastic* elongation before failure (see below). The weight of the material is also important - partly as a lead climber has the weight of the rope hanging below them, but also because climbing gear is often carried for large distances. Original climbing ropes were made of **hemp** - a natural fibre that is similar to **cotton**. Modern ropes are made of nylon, or combine a fibre core with a protective textile sheath (using **nylon** and **rubber**).

Ranking candidate materials

Two important material characteristics needed to satisfy the design requirements for climbing ropes are: (i) the elastic elongation to failure, and (ii) how much energy the rope can absorb by elastic stretching before breaking. These quantities are not separate material properties, but depend on two familiar properties – strength and Young's modulus – as follows:

elastic strain at failure = strength/Young's modulus

elastic energy stored at failure (per unit volume) = ½ x strength x elastic strain

Question 1

Use the data given below to calculate these quantities, and see if the materials used for climbing ropes have good values of failure strain and stored energy at failure. Using the data in the table, convert the figures you have calculated for stored energy per unit volume into stored energy *per unit mass*. When might this be a more useful property to use in selecting a material?

Question

Question 2

The silk spiders use to make their webs is also a natural fibre which has been used for thousands of years for exotic fabrics. Several companies have tried to mimic nature' s production process to produce this material artificially. Why might they wish to do this in commercial quantities? To help compare the properties, use the following data and the equations above to calculate specific strength, specific stiffness, elastic strain and stored energy per unit volume for webbing silk: Young's modulus = 11 GPa, strength = 1,000 MPa, density = 1,300 kg/m^3.

Question

Safety factors in design

For parachute lines and climbing ropes, where safety is the most important requirement, designers apply what is called a "safety factor". If you design a product that has to be strong and design it to survive to 5 times the expected maximum load, this is a safety factor of 5.

Question 4

Think of as many applications as you can of ropes, cables or wires which are designed to carry tensile loads. Which products would you design with the highest safety factors, and why?

Question

	Young's modulus (GPa)	Density (kg/m^3)	Strength (MPa)
Cotton	7.9	1,540	225
Hemp	32	1,490	300
Bulk Polyester	2.9	1,300	50
Bulk Nylon	2.5	1,090	63
Carbon Fibre	300	1,770	3,430
Aramid Fibre	124	1,450	3,930
Polyester Fibre	13.2	1,390	784
Nylon Fibre	3.9	1,140	616
Alloy Steel	210	7,800	1,330

Try it yourself 1

Collect samples of many different types of rubber bands and test the amount of elongation before failure. Is there a difference depending on the age of the rubberband, or the length or cross-sectional area of the rubberband? How is this property affected if there is a small cut in the rubberband?

Try it yourself

Question 3

It may not be possible to make a single strand rope thick or long enough. Human hair has been used to make ropes when other resources were not available: the isolated Islanders of St Kitts used to make them to abseil down the cliffs to steal birds eggs; Japanese monks in the 13th century made them over 10 inches in diameter to lift bells weighing more than 120 tons. Use the data above to calculate what size solid alloy steel cable would be needed to lift this size bell. Find out what size steel cable is recommended for this load and use this to estimate the safety factor that has been used.

Question