Journal of Physics Special Topics

An undergraduate physics journal

A1 5 Friendly Neighbourhood Spider-Man

C. Tang, L. Armitage, M. Alexander

Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH

December 12, 2023

Abstract

In this paper, we take the iconic train scene from *Spider-Man 2* (2004), where Spider-Man slows down a train that's about to fall off the track by using his web, saving everyone inside. We use this to estimate that the web undergoes a tensile stress of 2.9×10^8 N m^{-2} and has a Young's modulus of 6.2×10^7 N m^{-2}.

Introduction

Spider-Man 2 takes place in New York City, USA. Halfway through the movie, the villain Doctor Octopus is fighting the titular hero Spider-Man on a New York City subway train. During the fight, Octopus destroys the brakes of the train. The train is approaching the end of the track, where it will fall and plunge into water, killing the innocent passengers inside. Spider-Man stands at the front and shoots his web at nearby buildings, using it to slow the train down. The train comes to a complete stop, seconds away from it falling. For this to work, the web must be very durable, so what are its properties?

Assumptions

In the scene, Spider-Man shoots many webs at different buildings. This is a very complex situation, so we assume:

- Spider-Man shoots 1 strand of web from each hand simultaneously at nearby buildings. The web strand's original length l is 100 m, and has cross-section radius r of 0.01 m.
- The train slows down from velocity v_0 of 25 m s^{-1} [1] to a complete stop ($v = 0$ m s^{-1}) over a time t of 45 seconds at constant deceleration, and with no friction.
- The train is an 8 car R46 train, with a total mass m of 3.2×10^6 kg. [1].
- The web stays below its proportional limit, so Hooke's law is true.

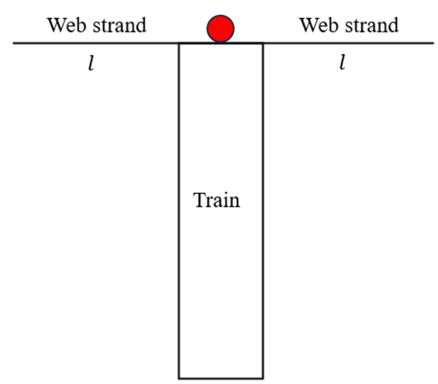

Figure 1: The system at $t = 0$ s. Spider-Man's location is the red circle.

Calculations

First we start with the train's movement, which is in only one dimension. It experiences a constant acceleration a opposite to the direction

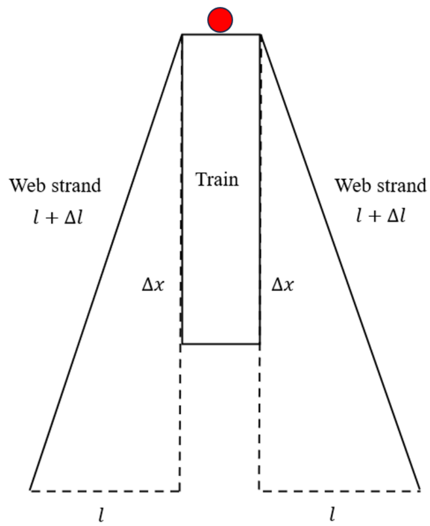

Figure 2: The system at $t = 45$ s. Spider-Man's location is the red circle.

of velocity, where $a = \frac{\Delta v}{t}$. As $\Delta v = -25$ m s^{-1} and $t = 45$ s, a has a value of -0.56 m s^{-2}. Substituting this and the total mass m into Newton's Second Law gives a total force $2F = ma = 180000$ N (total 2F as there are 2 identical web strands). Each strand experiences half of this, so $F = 90000$ N.

To calculate tensile stress, we also need the web strand's cross-sectional area, which can be calculated by substituting the radius r into the area of a circle $A = \pi r^2$, resulting in A being 3.1×10^{-4} m^2. The tensile stress of the web strand is simply F/A, equalling 2.9×10^8 N m^{-2}.

We also want to calculate the strain, which is the fractional change in length, $\frac{\Delta l}{l}$. To calculate the change in length Δl, we first need the final length of the web. As the train slows down, it travels a total distance Δx. By substituting the values of v_0, v and t into the following kinematic equation,

$$\Delta x = \frac{v_0 + v}{2t} \tag{1}$$

we obtain a distance of 560 m. Using Pythagoras' Theorem $(\Delta l + l)^2 = (\Delta x)^2 + l^2$, we get a total length $\Delta l + l$ of 570 m. Subtracting initial length l of 100 m away from this gets the change in length Δl of 470 m. Substituting this back into the strain, $\frac{\Delta l}{l}$ results in a strain of 4.7.

We can also calculate Young's modulus Y (N m^{-2}), which is the ratio of stress and strain, by using the following equation:

$$Y = \frac{F/A}{\Delta l / l} \tag{2}$$

Substituting all necessary values into Equation (2) gives the Young's modulus Y a value of 6.2×10^7 N m^{-2}.

Conclusion

Overall, Spider-Man's web is an amazing material. It experiences a tensile stress of 2.9×10^8 N m^{-2} without permanent deformation. This is comparable to the yield strength (maximum tensile stress before permanent deformation) and ultimate tensile strength of materials such as several types of steel, cast iron, and aluminium alloys [2]. However, its Young's modulus of 6.2×10^7 N m^{-2} is orders of magnitude lower than those materials, instead being more comparable to rubber [3] (which has an ultimate tensile strength of only 1.6×10^7 N m^{-2} [2]).

These unique properties make Spider-Man's web a perfect material to slow down the train with. Typical stretchy materials would not withstand the immense force as their ultimate tensile strength is too low. Also, strong materials such as metals typically cannot stretch very far, meaning the train has to decelerate over a short distance and in a short time. This means it has to withstand even more force (as a in $F = ma$ is larger), either breaking the material outright or decelerating the train too quickly, which would result in it crashing.

References

[1] https://en.wikipedia.org/wiki/R46_(New_York_City_Subway_car)

[2] https://en.wikipedia.org/wiki/Ultimate_tensile_strength

[3] https://en.wikipedia.org/wiki/Young%27s_modulus [All Accessed 30/10/23]