Thread pulling on a stone-hanging thread

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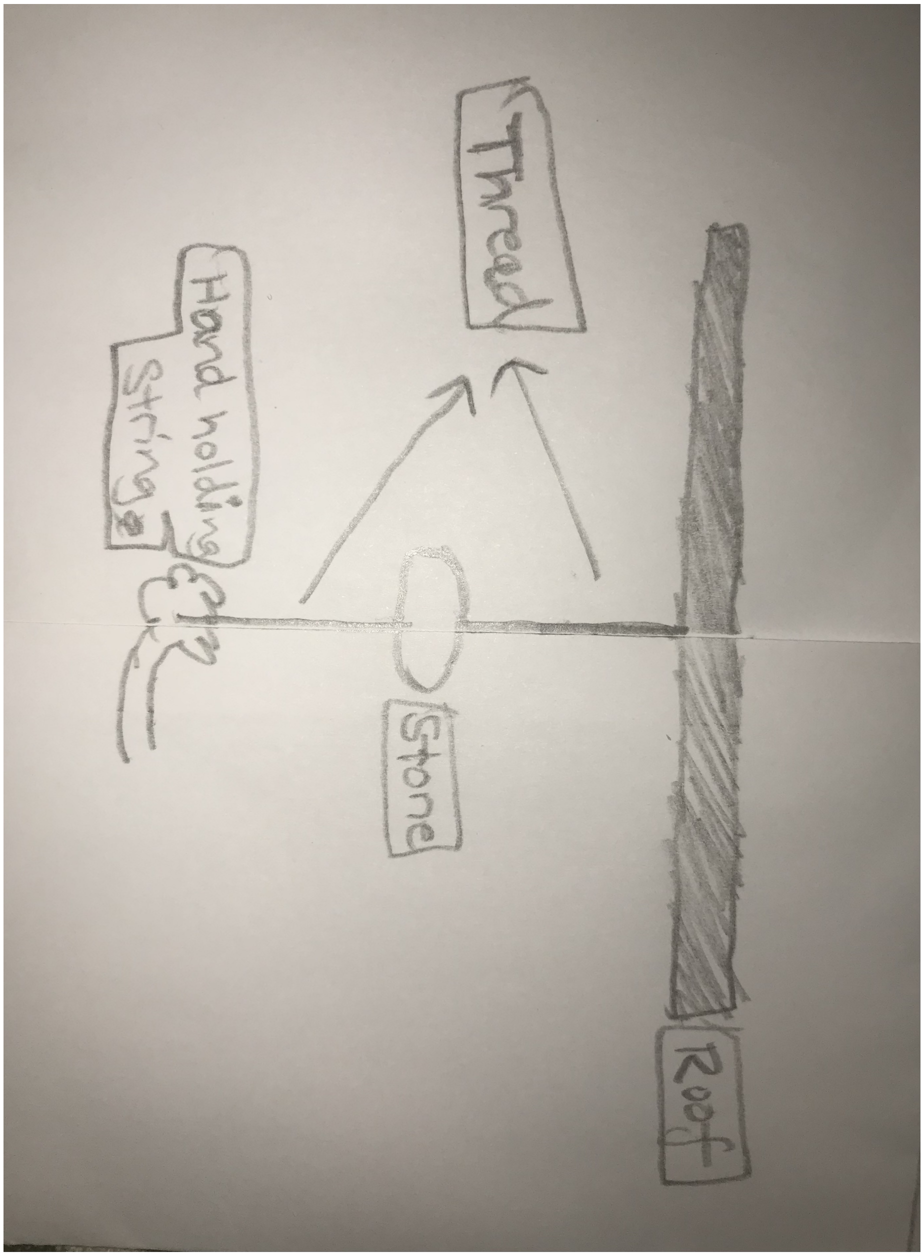
1 A classic physics problem

A stone hangs by a fine thread from the ceiling, and a section of the same thread dangles from the bottom of the stone. If a person gives a sharp pull on the dangling thread, where is the thread likely to break: below the stone or above it? What if the person gives a slow and steady pull?

2 Diagram



3 Notation

We'll introduce some notation so that we can refer to specific objects easily.

Call the stone object $\mathcal{S}$. Let the thread above the stone be called $\mathcal{P}$, and the thread below the stone be called $\mathbb{Q}$. Let the tension in $\mathcal{P}$ be T_p and the tension in $\mathbb{Q}$ be T_q. Let the mass of $\mathcal{S}$ be m, and let the force of gravity be g. Call the maximum tension the thread can hold, after which it will break x.

4 Solution to part one

When we give a 'sharp pull' in one go, we try to pull $\mathbb{Q}$ down, which tries to pull $\mathcal{S}$ down, which tries to pull $\mathcal{P}$ down, which tries to pull the ceiling down. However, since we are exerting such a large force in an instant, there isn't all the time to do this; the immediate reaction to this force is different than expected.

When you pull $\mathbb{Q}$ sharply, $\mathcal{S}$ doesn't have time to first overcome it's inertia and then accelerate along with the string, so then for an instant $T_q > x$. Because of this, the bottom thread breaks.

In simple terms, the bottom thread wants to go down because of the pull, but the rock is taking time to overcome it's inertia, and till the time it will overcome it, the bottom thread will break as it is being pulled from both sides: the rock and the hand pull. □

5 Solution to part two

When we pull $\mathbb{Q}$ 'slow and steady', then the tension in $\mathbb{Q}$ and $\mathcal{P}$ keep increasing, until at one instant one of them breaks.

Note that until that one instant, $\mathcal{S}$ is at rest. Thus, until that instant, the net forces on it must sum to zero. That is,

$$F_p - F_q - mg = 0.$$

since the tension in the thread above the stone pulls the stone upwards, while the tension in the bottom thread pulls the stone downward. Also, since the stone has weight, gravity pulls it at a force of $F = ma = mg$.

This equation simplifies to

$$F_p = F_q + mg.$$

Since mg, F_p, and F_q are all positive, F_p is always greater than F_q. In other words, the tension in the thread above the stone reaches x before the bottom thread does. And that's why the thread above will break first. □